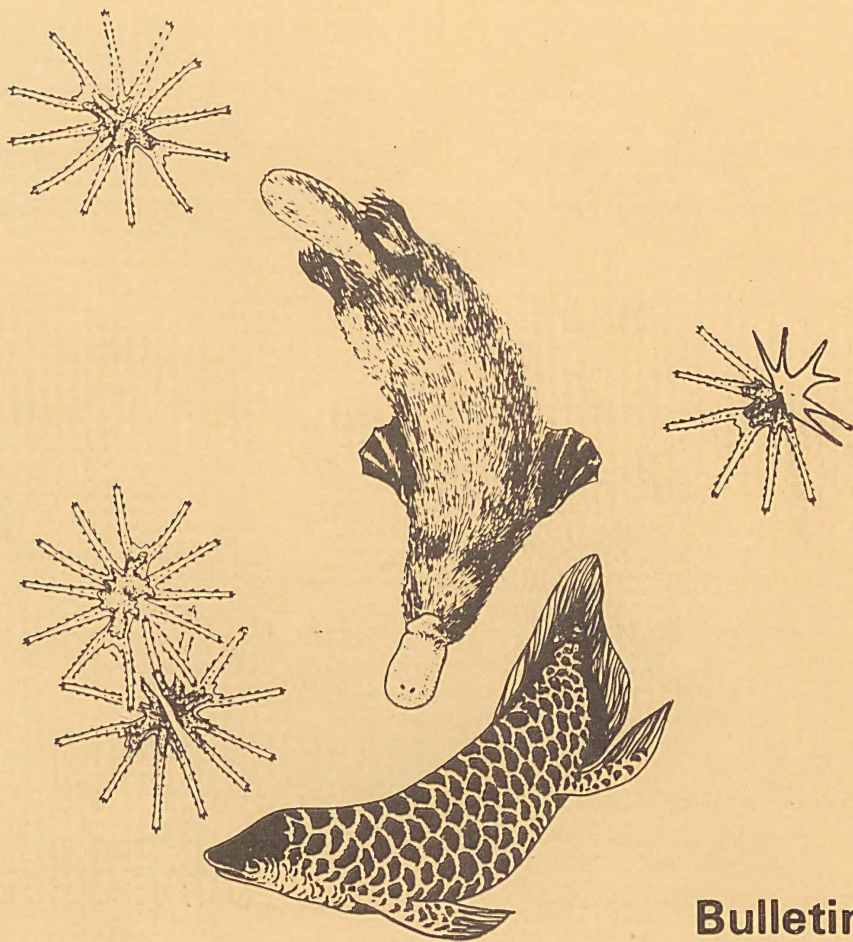


Australian Society for Limnology



**Bulletin
No. 8**

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**BULLETIN OF THE AUSTRALIAN
SOCIETY FOR LIMNOLOGY No. 8, DECEMBER 1982**

Edited by R.W.G. White

P.S. Lake The 1981 Jolly Award Address — Ecology of macroinvertebrates of Australian upland streams — a review of current knowledge. **1**

P.L. Cadwallader and A.K. Eden Observations on the food of rainbow trout, *Salmo gairdneri* Richardson, in Lake Purrumbete, Victoria. **17**

W. Fulton Notes on the distribution and life cycle of *Paranaspides lacustris* Smith (Crustacea: Syncarida). **23**

J.R. Merrick and S.H. Midgley Techniques for collecting and culturing eggs of two sleepy cod species in the genus *Oxyeleotris* (Perciformes: Eleotridae) **27**

P.S. Lake The relationships between freshwater fish distribution, stream drainage area and stream length in some streams of south-east Australia. **31**

S.J. Smith and R. Swain Observations on the taxonomy of *Austrochiltonia* (Hurley) (Amphipoda: Ceinidae). **39**

The 1981 Jolly Award Address 'Ecology of the Macroinvertebrates of Australian Upland Streams — A Review of Current Knowledge'¹

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I. INTRODUCTION

Flowing waters or lotic environments were the dominant type of freshwater environment in Australia prior to the invasion of Australia by white men. I say 'were' for it is now debatable as to whether this dominance still holds, given the incessant damming activities of modern Australians. Australian limnology has and still is dominated by the study of standing water bodies (Bayly and Williams 1973). The neglect of lotic ecology still persists even though many now realize that rivers such as those of the Murray-Darling system, upon which we place great economic demands, are deteriorating both in terms of ecological integrity and economic value. We have many limnological studies of impoundments but only a few of the rivers from which the impoundments were formed.

Upland creeks bordered by tea-tree and tree-ferns, and meandering rivers overhung with river red gum, are peculiar to Australia and we know precious little about them scientifically. Along with our ignorance of lotic ecology in Australia there has been a sad neglect of the effective conservation of Australian lotic environments (Lake 1978, 1980).

In this paper I discuss the fauna of upland streams (the eroding sections of rivers) rather than that of large lowland rivers (the depositing sections of rivers).

It is hard to generalize about the distinctive features of Australian eroding streams, but two referred to previously (e.g. Williams and Wan 1972; Bayly and Williams 1973; Hynes and Hynes 1975; Williams 1976, 1980; Winterbourn 1980), warrant attention. Reflecting the aridity of Australia and its latitude, it is clear that many of our streams undergo great variations in flow. Some variations in flow may be regular (for example, the effect of the wet season in tropical Australia v. Beumer 1980). Others, as in arid Australia, may be quite irregular as droughts break and normally dry rivers flow briefly. Coupled with this variation in flow is the oft-observed fact that many of our rivers may cease to flow in summer or the dry season (Morrissy 1967, 1979; Beumer 1980; Bycroft *et al.* 1981; Jeffree and Williams, 1981) and become a series of discrete pools. In such pools, conditions familiar to lentic limnologists may arise, such as thermal stratification (Morrissy 1967), oxygen depletion (Morrissy 1978, 1979; Bycroft *et al.* 1981), an increase in salinity (e.g. Norris 1972; Bennisson 1975; Morrissy 1979) and even halocline formation (Morrissy 1979). Thus the very variable flow patterns and intermittent nature of the flow impose very taxing conditions on Australian stream animals.

A second distinctive feature is that, in the natural state, our streams are surrounded and often enveloped by a catchment of sclerophyllous evergreen vegetation dominated by the families Myrtaceae, Leguminosae, Proteaceae and Casuarinaceae. For forested upland streams, many Northern Hemisphere limnologists now accept the dictum that in terms of energy metabolism such streams are heterotrophic and dependent basically for their energy on the input of allochthonous organic matter. Many workers have regarded our streams in intact catchments as being heterotrophic (e.g. McMichael 1952; O'Farrell 1949; Blackburn 1976; Blackburn and Petr 1979; Barmuta 1978; Williams 1976; Williams

1. This paper was read at the Annual Conference of the Australian Society for Limnology at Narooma, N.S.W. on 24 May 1981. Dr Lake was the recipient of the 1980 Jolly Award.

and Wan 1972). The supposedly aseasonal pattern of leaf-fall, combined with the uncertain climate of Australia, are supposed to have given rise to flexible life history patterns and broad niches in Australian stream invertebrates. Furthermore, the poor niche differentiation and the flexible life history pattern are held to have lead to a reduced species diversity in Australian stream communities in comparison with that in Northern Hemisphere temperate streams (Williams and Wan 1972; Hynes and Hynes 1975; Williams 1976, 1980; Winterbourn 1978, 1980).

A final point about the distinctiveness of Australian streams concerns vertebrate predators. Most Australian freshwater fish are stream dwellers, but in comparison with every other continent our waters hold a very low number of freshwater fish species. This paucity of fish species does not appear to mean a low fish biomass (see Fletcher 1979; Lake and Fulton 1981), but rather suggests that the fish are not very specialized with respect to food. True herbivorous fish are absent; the fish are macroinvertebrate predators and piscivores. What are the effects on the structure of the macroinvertebrate community of being preyed upon by a small number of species of generalists as opposed to larger number of species of specialists?

Australian stream animals have had to adapt to a set of environmental conditions very different from those anticipated by the tenets of classical Northern Hemisphere limnology.

II. STREAM CLASSIFICATION AND ZONATION

For streams in Europe, Africa and America the zonation scheme of Illies (1961) and Illies and Botosaneanu (1963) has been found to be applicable. However in some quarters, e.g. U.S.A., the application of the scheme has been questioned (Pennak 1979). Williams (1976) urged that the applicability of Illies' generalized zonation scheme to Australian streams be tested. Investigations of the physico-chemical parameters and biota of streams in Victoria (MacMillan 1975; Gooley 1977; Malipatil and Blyth 1982) and in Tasmania (Bennison 1975; Hay 1977) have found that while an upland rhithron section of a stream can be differentiated from a lowland potamon section, the boundaries between the two sections are not discrete but diffuse. Also, these workers found that when biota and physicochemical conditions were treated together, there were no clear subdivisions of the rhithron zone into epi-, meta- and hypo-rhithron. Possibly a simple division into two major regions with a 'grey' area between, without the restrictions of Illies definition, is telling us simply that there is an eroding zone, an intermediate zone and a depositing zone of streams (Shelford and Eddy 1929; Cummins 1972). This latter scheme may be more applicable to Australian streams, where one may have a rheophilous, eurythermal biota dwelling in warm, running, turbulent, well-oxygenated waters.

For United States streams, Pennak (1971, 1979) has suggested that the recognition of stream categories be based on a multiple set of criteria. Those criteria include such characteristics as width, flow, current speed, substratum, summer temperatures, winter temperatures, turbidity, total dissolved organic matter, water hardness, dissolved oxygen, rooted aquatics and streamside vegetation. Such a procedure could be adopted for Australian streams incorporating the additional criterion of period and variability of flow.

III. STREAM INVERTEBRATE TAXONOMY

As for virtually all invertebrate ecological studies in Australia, the 'taxonomic impediment' hinders progress in lotic ecology; some would say especially in lotic ecology. In lotic systems in particular the fauna is insect-dominated and most of the insects present

are nymphal or larval stages. Matching nymphal stages with adults is often difficult; matching larvae with adults is simply not possible for many taxa at present. I agree with Blyth (1979) that identifications of the immature forms of insects collected in invertebrate surveys is a high priority, even if such identification refers only to voucher specimens in recognised museums. The realization of such a priority along with distributional and environmental data would be of immense value to the precision of all future surveys and to the development of a zoogeographical understanding of our aquatic insect fauna. Even though there is an uncertainty about much of our taxonomy, this should not be used as an excuse for curtailing or, indeed, torpedoing correlational or manipulative ecological studies of the invertebrates of Australian streams.

Table 1. The status of taxonomic knowledge of macroinvertebrates of Australian streams. Modified from Williams (1976) and Campbell (1981).

	Adults			Nymphs/Larvae		
	I	II	III	I	II	III
Porifera			*			N.A.
Cnidaria	*					N.A.
Platyhelminthes						
Turbellaria			*			N.A.
Nematomorpha	*					N.A.
Nematoda	*					N.A.
Annelida						
Oligochaeta	*					N.A.
Hirudinea		*				N.A.
Mollusca						
Bivalvia		*				N.A.
Gastropoda		*				N.A.
Arthropoda			*			
Crustacea						
Isopoda		*				N.A.
Amphipoda		*				N.A.
Decapoda		*				N.A.
Hydracarina	*					N.A.
Insecta						
Plecoptera		*			*	
Ephemeroptera		*		*		
Odonata			*		*	
Megaloptera			*		*	
Neuroptera/Mecoptera		*		*		
Trichoptera		*		*		
Hemiptera		*			*	
Coleoptera						*
Dytiscidae			*			*
Hydrophilidae		*		*		
Helminthidae		*		*		
Psephenidae		*		*		
other Coleoptera		*		*		
Diptera						*
Blephariceridae		*				*
Chironomidae		*		*		
Culicidae		*		*		*
Simuliidae		*		*		*
Tipulidae		*		*		*
other Diptera	*			*		

I = Little taxonomic information.

II = Not well known taxonomically but there may be fairly complete regional studies, or studies of particular genera.

III = Relatively well known taxonomically.

N.A. = Not applicable.

Drawing attention to the parlous state of much of the taxonomy of Australian freshwater invertebrates, Williams (1976) drew up a table summarizing the state of taxonomic certainty which then operated. Fortunately the situation has improved since then. Campbell (1981) has recently compiled a new taxonomic table for stream macroinvertebrates which I have in turn modified (Table I).

IV. SURVEYS OF INTACT STREAMS

Comprehensive surveys of the invertebrates have been carried out in a relatively small number of intact Australian streams. The principal reason for these surveys has been that the stream in question is threatened with development, usually dam construction. Up to the early seventies, as a result of a preoccupation with stream pollution, we knew more about the biota of polluted streams than intact ones. Table 2 is a provisional list of intact, unpolluted streams that have been surveyed and may be judged as giving a good indication of the variety and number of taxa present in the stream systems.

This list is very provisional and as much of the information is in unpublished theses or relatively inaccessible environmental impact surveys, there is no doubt that I have missed some surveys of intact streams. Not surprisingly, the number of taxa varies tremendously, dependent on such things as sampling effort, duration of sampling period and type of collecting equipment used.

Two significant points do emerge from these surveys. First there is an increase in the number of taxa with the size of the streams and its catchment. From three small order 1 creeks in Victoria, Robinson (1977) collected 107 taxa; from a small order 2, fast-flowing coastal creek in Victoria, Yule (1978) collected 182 taxa; while from the Thomson and Macallister Rivers, Malipatil and Blyth (1982) collected 528 taxa. Second, in comparison with comparable studies of small to large river systems in northern temperate regions, there is no suggestion that the stream fauna, at least in south-eastern Australia, is depauperate. For upland streams in south-eastern Australia, even though the number of plecopteran and ephemeropteran taxa may be lower than expected from Northern Hemisphere criteria, this deficiency is more than made up by a richness of Trichoptera, Diptera (chironomids) and Coleoptera (elmids).

V. AUTECOLOGY OF AUSTRALIAN STREAM MACROINVERTEBRATES

Moving on to consider the attributes of single species, and whether these reflect the unusual nature of Australian stream ecosystems, it becomes immediately apparent that in terms of physiology, ethology and life history we know very little indeed.

Working with five species of larval Trichoptera from southern Queensland, Korboot (1963) determined upper and lower thermal death points. Not surprisingly the upper thermal death points were relatively high (e.g. 38°C for *Anisocentropus latifascia* (of the family Calamoceratidae). She investigated the effects of temperature and different light regimes on larval and pupal development. Interestingly, she determined the minimum oxygen tolerances of the larvae and found that larvae of the hydropsychid *Cheumatopsyche modica* which lives in strong currents expired at oxygen concentrations below 9 p.p.m.

Studies of activity have been carried out on two species of Ephemeroptera. Campbell (1980) found that there is a nocturnal peak in surface activity of the nymph *Mirawara purpurea* and suggested that in the daytime the animal is to be found in the hyporheos. Bailey (1981b) found that the activity of the nymph *Atalophlebioides* sp. peaked at midnight when the animals were on the surface of their stones. In an elegant study, Smith and Dartnall (1980) investigated the means by which psephenid larvae of the genus *Sclerocyphon* stabilized the boundary layer. The system of boundary layer stabilization

Table 2. Published surveys of the ecology of upland streams and rivers in Australia.

Type	Locality	Investigator
Small coastal stream	Warrah Creek, near Sydney, N.S.W.	McMichael 1972
Small intermittent streams	Tuggeranong Creek and Village Creek near Canberra A.C.T.	Norris 1972
Small coastal stream	Painkalac Creek near Airey's Inlet, southern Victoria.	Yule 1978
Small forest streams	Piccaninny Creek, Slip Creek, and Blackjacket Creek near Healesville, Victoria.	Robinson 1977
Small/medium forest streams	East branch of Barwon River and above and below Lake Elizabeth, Otway Ranges, Victoria.	Aldenhoven 1975
Medium/large upland river	Acheron River, southern central Victoria.	MacMillan 1975; Doeg 1979
Medium upland river	Gara River, near Armidale, northern N.S.W.	O'Farrell 1949
Medium/large upland rivers	Upper Shoalhaven and Mongarlowe Rivers, southern Tablelands, N.S.W.	Bishop and Tilzey 1978
Small/medium/large upland and coastal rivers	Lower Gordon and Franklin Rivers and tributaries, Tasmania.	Richardson and Swain 1978; Coleman 1978
Medium/large upland river	Mitta Mitta River, north-eastern Victoria.	Smith, Malcolm and Morrison 1976, 1977, 1978
Medium/large upland rivers	Mitchell River and Wentworth River near Tabberabbera, south-eastern Victoria.	Ahern and Blyth 1978
Medium/large upland rivers	Thomson and Macallister Rivers, southern and central Victoria.	Melbourne and Metropolitan Board of Works 1975; Blyth 1979

they demonstrate allows the larvae to exploit food resources on rocks at high current velocities.

Returning to the question of the vagaries of physico-chemical conditions in Australian streams, and the presumed aseasonality of allochthonous energy input, it is unfortunate that only a few studies of life histories have been made.

In small streams of southern Queensland Korboot (1963) found that the hydropsychid trichopteran *Cheumatopsyche modica* and the leptocerid trichopteran *Symphitoneuria exigua* were bivoltine with relatively long periods of adult emergence. Less intensive field observations on four other species of Trichoptera (*Helicopsyche tillyardi*, *Triplectides volda*, *T. australis*, *Anisocentropus latifascia*) also revealed extended periods of adult emergence. In two small Victorian streams, Duncan (1972) investigated the life histories of six species of Ephemeroptera. All six species were univoltine with adult emergence in summer. Only one species, a siphonurid *Coloburiscoides giganteus* from Chalet Creek, Mt. Buller had a well synchronised, precisely timed life history. No evidence of seasonal succession was found with the five species co-existing in Chalet Creek. In a very comprehensive study, Hynes and Hynes (1975) investigated the life histories of 34 species of plecopterans at 11 localities in Victoria. Very few species (*Thaumatoperla* spp., *Newmanoperla thoreyi*) displayed a regular, precisely timed life history. Rather many species, especially in the genera *Riekoperla* and *Dinotoperla*, displayed a great flexibility

in life history timing. Hynes and Hynes (1975), and Hynes (1976) felt that this flexibility in life history timing is an adaptation to the vagaries of Australian stream conditions. Such flexibility they felt 'has probably reduced the total number of niches available on the continent' (for Plecoptera at least).

Yule (pers. comm.) has verified the flexibility and opportunism in life history of *Dinotoperla* species, with perhaps the greatest opportunism being displayed by *Dinotoperla bassae* which lives in temporary ponds and can complete its life history in eight weeks. Such have been the selection pressures for an opportunistic life cycle that in Australia we have a temporary pond stonefly — a most unusual environment for stoneflies. For two species of *Tasmanoperla* (Austroperlidae), Waterhouse (1980) found flexibility in life history timing with *T. larvalis* being more flexible than its congener *T. thalia* which occurs at higher altitudes.

Flexibility in life history timing and pattern seems to be present in at least two other orders of stream insects. In South Australia, Suter and Bishop (1980) found that the life cycles of the ephemeropterans *Tasmanocoensis tillyardi* and *Baetis soror* were most unusual from a Northern Hemisphere perspective (v. Landa 1968), and their data suggest considerable pliability in life history pattern. Zwick (1977) determined four types (winter, early summer, late summer and perennial) of life cycle for Australian blepharicerids. In the perennial type, exemplified by such a common and widely distributed species as *Edwardsina polymorpha*, there is a considerable flexibility in life history timing. For subtropical simuliids, the data of Colbo and Moorhouse (1979) suggest considerable flexibility in life history timing. In a recent study, Towns (1981) describes the life histories of 12 species of macroinvertebrate (1 gastropod mollusc, 1 amphipod, 10 species of insects) from a Kauri forest stream, the Waitakere River, in the northern part of the North Island of New Zealand. For all species he found that the life cycles were non-seasonal, a pattern which seems to hold for most New Zealand freshwater macroinvertebrates so far studied.

On the other hand Hay and Ball (1979) have reported regular annual life cycles for planarians living in Victorian upland streams, and the same is apparently true for the stream crustaceans that have been so far examined (*Paratya australiensis* (Walker 1972; Williams 1977), the phreatoicid *Colubotelson thomsoni* (Knott 1971), and the amphipods *Pseudomoera gabrieli* and *Austrochilontia australis* (Smith and Williams 1980)). The need for flexibility in life history timing may be more pressing for insects because the immature insects have to adapt to the uncertainties of the Australian freshwater environment, and the adults have to adapt to the vagaries of the Australian terrestrial environment.

VI. STREAM DRIFT

As mentioned before, both Campbell (1980) and Bailey (1981b) found that species of ephemeropterans were more active on the surface of rocks at night, and in the case of *Atalophlebioides* sp. the nocturnal peak of activity occurred when the animals were also an important (dominant) part of the drift (Bailey 1981a, b). At Monash University, for the past three years, we have been working on the fauna of rocks in upland streams. As part of this work, Graesser (1980) investigated the stone fauna of the Toorong River near Noojee, Victoria, and found that the animals on rocks showed a diel periodicity in density reaching a minimum at night. This periodicity was negatively correlated with the diel density pattern of the drift fauna.

It is clear that, as in the other streams in the world, the phenomenon of drift occurs in Australian streams. McMichael (1952) sampled drift in Warrah Creek, but not over 24 hours. He found that it contained coleopterans, chironomids, ephemeropterans,

trichopterans, veliids, megalopterans, mites and water spiders. Morrissy (1967) observed the distinct nocturnal increase in drift density in his work on the food of trout in small South Australian streams. In still water and in pools at night, Morrissy (1967) found an increase in the density of animals in open water, thus showing that the phenomenon of drift is not simply one of animals passively using the current at night but rather of animals actively swimming.

In the upper Shoalhaven and Mongarlowe Rivers, Bishop and Tilzey (1978) found that Ephemeroptera, Trichoptera and Diptera dominated the drift. The lowest drift density and the lowest drift biomass occurred in winter during the period of maximum flow; while the benthos density remained relatively constant. This phenomenon may possibly be explained by a constant number of animals drifting but the density changing with volume of discharge.

During the total solar eclipse in southern Victoria beginning at 16.42 h on 23 October 1976, two groups of investigators monitored stream drift: Cadwallader and Eden (1977) at Snobs Creek and Suter and Williams (1977) at the Acheron River. They arrived at different conclusions for Suter and Williams (1977) did not detect any differences in the density and composition of the drift while Cadwallader and Eden (1977) did. The latter found that several taxa which are nocturnal drifters, e.g. Leptoceridae, Helodidae, increased in density during the eclipse, and day drifting taxa such as *Cricotopus* decreased.

Above and below the inputs of heavy metal pollution to two Tasmanian rivers, Lake *et al.* (1977), Norris (1978) and White *et al.* (1980) found that the drift changed substantially. The cause of the abrupt drop in drift density is unknown, though it is suggested that animals do not drift very far and are capable of migrating out of unfavourable environments. In Bulimba Creek in southern Queensland, Arthington and Conrick (1981) found that the entry of organic pollution from a sewerage farm into the creek greatly depleted the species richness and abundance of the drift. Bailey (1981a) investigated drift in a small stream near Canberra and found it to be predominantly a nocturnal phenomenon dominated by a leptocerid trichopteran, *Atalophlebioides* sp. and chironomid pupae. Ephemeroptera and Trichoptera were more prevalent at night while the chironomid pupae were more common in the day-time drift.

Given the variability of flow in Australian streams and the supposedly unusual nature of allochthonous energy input into out streams, an investigation of the phenomenon of drift in streams over a period of time may be very instructive. Does the flexibility of insect life history timing influence the composition of the drift? What compensates for the downstream movement of animals?

VII. ENERGY INPUT AND SEASONALITY

Studies on stream systems in temperate zones of the Northern Hemisphere have established the dictum that upland streams in forested catchments are heterotrophic (Cummins 1974; Mann 1975) with a marked seasonal leaf fall. The organic matter present in streams is commonly divided into three size classes: coarse particulate organic matter (CPOM), fine particulate organic matter (FPOM), dissolved organic matter (DOM) (Cummins 1974; Hynes 1975). Quantitatively CPOM is the dominant component entering the stream — the input being primarily leaf litter. The macroinvertebrates of upland streams have been classified into functional feeding groups — the shredders, the collectors, the scrapers, the piercers and the predators (Cummins and Klug 1979). In small upland wooded streams the shredders and the collectors dominate the biomass. The input of litter in autumn is reflected in an increase in the importance of shredders while the scrapers reach their maximum abundance in summer (Cummins and Klug

1979). There is thus an ordered sequence of species growing in the streams, with maximum growth and abundance occurring in winter and spring from the metabolising of the autumnal input of litter (e.g. MacKay and Kalff 1969; Egglshaw and MacKay 1967; Minshall 1968; Hynes 1970; Slobodchikoff and Parrott 1977). While abundance peaks in summer, the number of species reaches a maximum in late summer-autumn (e.g. MacKay 1969; Hynes 1970; Slobodchikoff and Parrott 1977; Andrews and Minshall 1979).

Table 3. The timing and quantity of leaf fall in some Australian forests.

Forest Type	State	Dominant Species	Amount t ha ⁻¹ yr ⁻¹	Time of year	Investigator
Rainforest	Qld	Notophyll vine forest	10.06	Oct-Dec	Plowman 1979
Wet sclerophyll	Qld	<i>Eucalyptus saligna</i>	9.77	Nov-Jan	Plowman 1979
Wet sclerophyll	Qld	<i>E. signata</i>	7.05	Nov-Feb	Rogers & Westman 1977
Wet sclerophyll	Vic	<i>E. regnans</i>	7.66	Dec-Mar	Ashton 1975
Wet sclerophyll	Vic	<i>Nothofagus cunninghamii</i>	6.50	Mar	Howard 1975
Wet sclerophyll	Vic	<i>E. obliqua</i>	3.60-5.50	Dec-Mar	Attiwill 1968; Attiwill <i>et al.</i> 1978
Paperbark forest	W.A.	<i>Melaleuca cuticularis</i>	4.74	Jan-Apr	Congdon 1979
Open forest	Qld	<i>E. umbra</i> and <i>E. baileyana</i> and <i>Angophora woodsiana</i>	1.80-3.60	Dec-Mar	Birk 1979

As mentioned before, a number of writers (e.g. Williams and Wan 1972; Hynes and Hynes 1975; Williams 1976, 1980) have felt that the observed flexibility of life histories of Australian stream insects is related to the unpredictable nature of the climate and the lack of a seasonal leaf-fall from the evergreen flora. However, numerous studies have shown that Australian forests do have a distinct seasonal leaf fall — in summer (Table 3). The pattern seems to hold from paperbark forest woodland and wet sclerophyll forest to temperate and subtropical rainforest. While the season of leaf fall may not be as sharp as deciduous forest it is similar in the humped shape of its peak to conifer forests in both the Northern Hemisphere (Bray and Gorham 1964) and Australia (Spain 1973). The marked seasonality in the litter fall of Northern Hemisphere deciduous forests may have been, however, over-emphasised. For example, at Hubbard Brook, Gosz *et al.* (1972) found that the autumn peak only contributed 49.7 per cent of the annual total litter fall, while winter and summer both contributed just over 20 per cent each. In comparison, in *Eucalyptus obliqua* forest in Victoria, over 70 per cent of the total annual leaf fall is in the summer peak (Attiwill 1968; Attiwill *et al.* 1973).

There is one further qualification to bear in mind concerning the litter fall of some types of Australian forests and it concerns bark and branches. In those species of eucalyptus, e.g. *Eucalyptus regnans*, which annually decorticate, bark and branches may be a very important component of the litter (Bray and Gorham 1964). Along Australian rivers, notably in the depositing section, grow river red gums (*Eucalyptus camaldulensis*) which have the hazardous habit of dropping complete limbs, almost explosively, particularly during hot weather. The shedding of bark and branches, as in the Northern Hemisphere (e.g. Gosz *et al.* 1972), is a function of meteorological conditions and is not strictly seasonal. Thus at the equinoxes in Australia, the time of strong winds, there may be a considerable fall of bark and branches. Concerning litter fall in Australian forests, the quantities are in good agreement with world-wide figures (Bray and Gorham 1964) (Table 3); there is a peak of litter fall (summer) and in some forests bark and branches may be an important though not dominant part of the litter.

Returning to the nature of energy inputs to upland Australian streams in forested catchments, a number of workers (e.g. O'Farrell 1949; McMichael 1952; Metzeling 1977; Robinson 1977) have suggested that allochthonous input is important while Blackburn (1976), Blackburn and Petr (1979) and Barmuta (1978) have shown that allochthonous organic matter is important. Blackburn's study in Cement Creek in southern Victoria was carried out over winter and spring. She found that bark and branch litter contributed more biomass and energy to the stream than leaves. She calculated a processing rate expressed as the percentage of total calorific value lost from litter input after one month's submersion in the stream, and found that the processing rate for *Eucalyptus* leaves was 70 per cent, for *Nothofagus* leaves it was 68 per cent, while for bark it was only 23 per cent. Thus leaves may be utilized on a relatively short-term basis (c. 2 months) while bark and branches are broken down and metabolized very slowly. In South Australia, Barmuta (1978) investigated the metabolism of *Eucalyptus obliqua* leaf packs. He found that leaves of *Eucalyptus obliqua*, like those of *Eucalyptus regnans*, belonged to the medium processing groups of Petersen and Cummins (1974). In 90 days, 76 per cent of the initial pre-leached dry weight of the leaves was lost or metabolized. Experimental work suggested that bacteria may be more important in the breakdown of leaves, and that because of an absence of coarse shredders in the stream in winter, leaf breakdown may be principally by abiotic fragmentation.

In Commissioners Water on the New England Plateau, N.S.W., Pidgeon and Cairns (1981) used litter bags to investigate the decomposition of willow leaves, the aquatic macrophyte *Myriophyllum propinquum* and the leaves of the riparian trees *Casuarina cunninghamiana* and *Eucalyptus blakelyi*. Breakdown of the willow leaves and of *Myriophyllum* material was rapid, while that of the leaves of native trees occurred at a very slow rate (half life for *Casuarina* leaves in winter = 180 days, half life for *E. blakelyi* leaves in winter = 264 days), placing these two species in slow breakdown category of Petersen and Cummins (1974). Colonisation of the leaf material by stream invertebrates was rapid and the animals appeared to use the plant material primarily as a food source rather than a refuge. In comparison to overseas studies 'shredders' played a relatively unimportant role in leaf breakdown.

In Australian streams dependent on allochthonous energy input, there is a summer period of leaf litter fall which may be metabolised over late summer and autumn and from many forests there is a very substantial input into the streams of bark and branches which is metabolised slowly and may provide an energy substrate for a considerable part of the year. Thus in southern Australia our streams can be expected to have a seasonality very different from that of typical Northern Hemisphere upland streams in that readily accessible energy comes in at the period of low flow and high water temperatures. Furthermore, the metabolism of bark and branches may be carried out at a fairly constant rate all the year. In northern monsoonal Australia, the allochthonous energy input occurs in the wet season when stream flows are high.

Many streams have natural or man-affected sections of stream which are not enveloped by dense forest. Minshall (1978) makes the point that 'the idea of a general dependency of streams on allochthonous organic materials has been over-emphasised'. In a pioneer study of a small stream, Pidgeon (1978) examined energy flow levels and patterns at three sites on Commissioners Waters near Armidale. At a natural native woodland site, in comparison with a cleared site and a site infested with willows, annual gross primary production was highest ($19,082 \text{ kJ m}^{-2} \text{ yr}^{-1}$) and even though the woodland site was partly shaded it was highly autotrophic ($P/R = 1.22$). Allochthonous detritus input was highest at the willow infested site. The great differences in source and type of energy input appeared to have only minor effects on the composition of the benthos. The highest value of mean annual standing crop B and annual production P of the primary

consumer benthos were highest at the woodland site ($B = 169.8 \text{ kJ m}^{-2}$, $P = 1,521 \text{ kJ m}^{-2} \text{ yr}^{-1}$) compared with the cleared site ($B = 123.9 \text{ kJ m}^{-2}$, $P = 891.3 \text{ kJ m}^{-2} \text{ yr}^{-1}$) and the dense willow site ($B = 60.2 \text{ kJ m}^{-2}$, $P = 599.63 \text{ kJ m}^{-2} \text{ yr}^{-1}$). At the willow site a considerable amount of the detritus was not processed. Autotrophic production besides being the dominant energy input at the woodland site was also seasonal with spring and summer energy levels being higher than those of autumn and winter. Given the amount of Australian streams not overlain by dense canopies of evergreen growth, it is quite likely that a large number of our streams, even our upland streams, are autotrophic. There is no reason to expect these streams to be any less diverse and productive than heterotrophic streams (Minshall 1978). The seasonality in autotrophic production peaking as it does in spring and summer, may, as for leaf litter fall, impose forces shaping life histories in Australian stream communities different from those of Northern Hemisphere heterotrophic streams. It is interesting to note that Minshall (1978) feels that arguments '... attributing the synchronisation of life cycle phenomena in the benthic invertebrates to the autumnal input of allochthonous leaf material are not supported by evidence thus far.'

Australian heterotrophic streams differ from typical Northern Hemisphere streams both in the composition and timing of litter input. Energy input, be it autotrophic or heterotrophic peaks in summer and not in autumn. Our stream fauna may have different life history schedules from Northern Hemisphere species. The flexibility that has been observed in life histories may be, however, more fundamentally related to temperature and flow variability than to the supposed 'aseasonal' nature of the litter input. It may be that the unpredictable nature of annual stream temperatures in Australia in comparison with those of Northern Hemisphere temperate streams has given Australian stream insects their flexible life histories and may have given rise to more flexible communities lacking highly synchronized species complexes. It is interesting to note that recently evidence has been produced strongly suggesting that temperature (both amplitude and predictability) is of crucial importance to the structuring of stream insect life histories and communities (Vannote and Sweeney 1980). '*The predictability of stream temperature patterns (diel, seasonal and annual) are conducive to the development of communities that are both functionally predictable and highly structured.*' (Vannote and Sweeney 1980). Combined with this is the fact that many of our streams undergo great variations in flow volumes to which our stream fauna may also be adapted.

VIII. SPECIES RICHNESS

Evidence from stream surveys suggest that Australian streams do not have a depauperate fauna. Recently at Monash we have been investigating the species richness and diversity of Australian stream macroinvertebrates by investigating the fauna of rocks in upland streams. The fauna of stones is a discrete one which can be precisely sampled (Doeg 1979; Graesser 1980; Doeg and Lake 1981), and is amenable to experimental manipulation. In Tasmania preliminary investigations by Knott *et al.* (1978) have shown that the fauna of rocks in Hartz Creek was more diverse than that of littoral rocks from the adjoining Hartz Lake. Common taxa on the stones of the creek included *Austrosimulium victoriae*, *Atalaphlebioides* sp., *Cardioperla* sp., a chironomid and a helodid beetle. Doeg (1979) and Doeg and Lake (1981) have sampled for 12 months the stone fauna of the Acheron River. Overall, the dominant animals in terms of abundance are *Riekoperla williamsi*, *Agapetus* sp. and *Atalonella*. The dominant orders of insects are the Plecoptera (17 taxa) followed by the Trichoptera (15 taxa) and then Diptera (12 taxa). In all, 59 taxa of invertebrates were collected from the rocks at one site in the Acheron River. Seasonally the number of animals reached a maximum of 1073 animals m^{-2} in winter and a minimum in January-March. In terms of the number of taxa, a clear

trend is not evident although the lowest numbers of taxa were found in the summer of 1980. The drop in density in summer was due to substantial changes in the density of *Riekoperla williamsi*, *Agapetus* sp., *Paramoera fontana* and *Eukiefferella*. A clearer pattern emerges from our work over 2 years in the Toorong River, where the lowest numerical density and species richness occurs in January-March (summer). This pattern differs from that of typical Northern Hemisphere temperate streams in that summer has a depressing effect on both species richness and abundance, possibly due to low flow and adverse temperatures — even though leaf litter input and autotrophic production may be at maximum levels.

In the Acheron River the values for species richness are within the range expected for American temperate streams (Stout and Vandermeer 1976) but in the Toorong the number of taxa per collecting trip varies between 53 and 81 and in all we have collected 131 taxa. The Toorong River although being a temperate stream has a species richness equal to that of American tropical streams (Stout and Vandermeer 1976). The rock fauna is a rich one in both streams and is hardly one suggesting low speciation, reduced niche specialisation and a depauperate fauna.

In conclusion, the Australian stream invertebrate fauna, at least on the basis of limited work, is a diverse one. Even though there is considerable flexibility and aseasonality in the life histories of Australian stream invertebrates this is not correlated with a depauperate stream fauna. Our stream fauna, as opposed to that of Northern Hemisphere forest streams, has to cope with a summer litter fall though autotrophy may be more important in Australian upland streams than hitherto suspected. The great variability in stream temperatures, the high summer water temperatures and the variability in flow may be important influences shaping our stream macroinvertebrate communities.

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- Ahern, C.D. and Blyth, J.D. 1978. Mitchell River Environmental Study: Quantitative study of invertebrate fauna. In *Mitchell River Project: Supplementary Report on Environmental Studies*. State Rivers and Water Supply Commission, Victoria: pp. 1-175.
- Aldenhoven, J. 1975. *A Comparative Study of Stream Fauna Above and Below a Landslide Lake in the Otway Ranges*. B.Sc. Honours Thesis, Monash University.
- Andrews, D.A. and Minshall, G.W. 1979. Longitudinal and seasonal distribution of benthic invertebrates in the Little Lost River, Idaho. *Am. Midl. Nat.* **102**, 225-236.
- Arthington, A. and Conrick, D. 1981. Alternative approach to biological monitoring: sampling stream drift. *Aust. Soc. Limnol. Newsl.* **19**(3), 14.
- Ashton, D.H. 1975. Studies of litter in *Eucalyptus regnans* forests. *Aust. J. Bot.* **23**, 413-433.
- Attiwill, P.M. 1968. The loss of elements from decomposing litter. *Ecology* **49**, 142-145.
- Attiwill, P.M., Guthrie, H.B. and Leuning, R. 1978. Nutrient cycling in a *Eucalyptus obliqua* (L'Herit.) forest. I. Litter production and Nutrient Return. *Aust. J. Bot.* **26**, 79-91.
- Bailey, P.C.E. 1981a. Insect drift in Condor Creek, Australian Capital Territory. *Aust. J. Mar. Freshwater Res.* **32**, 111-120.
- Bailey, P.C.E. 1981b. Diel activity patterns in nymphs of an Australian mayfly *Atalophlebioides* sp. (Ephemeroptera: Leptophlebiidae). *Aust. J. Mar. Freshwater Res.* **32**, 121-131.
- Barmuta, L.A. 1978. *The Decomposition of Eucalyptus obliqua Leaf Packs in Small Stream Ecosystems*. B.Sc. Honours Thesis, University of Adelaide.
- Bayly, I.A.E. and Williams, W.D. 1973. *Inland Waters and their Ecology*. Longman Australia Pty Ltd, Camberwell.

- Bennison, G.B. 1975. *An Ecological Method of Classification of the Coal River in South-East Tasmania*. B.Sc. Honours Thesis, University of Tasmania.
- Beumer, J. 1980. Hydrology and fish diversity of a North Queensland tropical stream. *Aust. J. Ecol.* 5, 159-186.
- Birk, E.M. 1979. Overstorey and understorey litter fall in a eucalypt forest: spatial and temporal variability. *Aust. J. Bot.* 27, 145-156.
- Bishop, K.A. and Tilzey, R.D.J. 1978. *Welcome Reef Project, Environmental Study, Aquatic Life*. Metropolitan Water Sewerage and Drainage Board, Sydney.
- Blackburn, W.M. 1976. *A Study of Forest Litter in Relation to a Mountain Stream Ecosystem in Victoria*. B.Sc. Honours Thesis, Monash University.
- Blackburn, W.M. and Petr, T. 1979. Forest litter decomposition and benthos in a mountain stream in Victoria, Australia. *Arch. Hydrobiol.* 86, 453-498.
- Blyth, J.D. 1979. Freshwater Macroinvertebrate Surveys. In *Proceedings of a Symposium on Biology and Microbiology of Water, Canberra 25-26 August, 1977*, pp. 105-127. Department of National Development, Australian Water Resources Council, Canberra.
- Bray, J.R. and Gorham, E. 1964. Litter production in forests of the world. *Adv. Ecol. Res.* 2, 101-157.
- Bycroft, B.M., Coleman, D.J., Collier, B.A.W., Deacon, G.B., and Lake, P.S. 1981. *Heavy metals in Freshwater Streams — A Study of the Lerderderg Werribee Rivers System; Final Report*. Ministry for Conservation, Melbourne, Victoria.
- Cadwallader, P.L. and Eden, A.K. 1977. Effect of a total solar eclipse on invertebrate drift in Snobs Creek, Victoria. *Aust. J. Mar. Freshwater Res.* 28, 799-805.
- Campbell, I.C. 1980. Diurnal variations in the activity of *Mirawara purpurea* Riek (Ephemeroptera, Siphonuridae) in the Aberfeldy River, Victoria, Australia. In *Advances in Ephemeroptera Biology* (Eds J.F. Flannagan and K.E. Marshall) pp. 297-308. Plenum Press, N.Y.
- Campbell, I. 1981. Biology, taxonomy and water quality monitoring in Australian streams. *Water* 8 (4), 11-13 & 17.
- Colbo, M.H. and Moorhouse, D.E. 1979. The ecology of pre-imaginal Simuliidae (Diptera) in south-east Queensland, Australia. *Hydrobiologia* 63, 63-79.
- Coleman, D. 1978. *Downstream Effects of the Gordon Dam*. Lower Gordon River Scientific Survey No. 10. The Hydro-Electric Commission of Tasmania, Hobart.
- Congdon, R.A. 1979. Litter fall of the paperbark tree (*Melaleuca cuticularis*) in the marshes of the Blackwood River estuary, Western Australia. *Aust. J. Ecol.* 4, 411-417.
- Cummins, K.W. 1972. What is a river? — zoological description. In *River Ecology and Man* (Eds R.T. Oglesby, C.A. Carison and J.A. McCann) pp. 33-52. Academic Press, N.Y.
- Cummins, K.W. 1974. Structure and function of stream ecosystems. *Bioscience* 24, 631-641.
- Cummins K.W. and Klug M.J. 1979. Feeding ecology of stream invertebrates. *Ann. Rev. Ecol. Syst.* 10, 147-172.
- Doeg, T.J. 1979. *The Macroinvertebrate Fauna of Rocks in an Upland, Temperate Stream: Composition and Dynamics*. B.Sc. Honours Thesis, Monash University.
- Doeg, T.J. and Lake, P.S. 1981. A technique for assessing the composition and density of the macroinvertebrate fauna of large stones in streams. *Hydrobiologia* 80, 3-6.
- Duncan, M.J. 1972. *The Life Histories of Ephemeroptera from two Victorian Streams*. B.Sc. Honours Thesis, Monash University.
- Egglishaw, H.G. and Mackay, D.W. 1967. A survey of the bottom fauna of streams in the Scottish Highlands. Part III. Seasonal changes in the fauna of three streams. *Hydrobiologia* 30, 305-334.
- Fletcher, A.R. 1979. *Effects of Salmo trutta on Galaxias olidus and Macroinvertebrates on Stream Communities*. M.Sc. Thesis, Monash University.
- Gooley, G.J. 1977. *An Ecological Survey of the Bass River and Other Streams in the Westernport Bay Catchment*. B.Sc. Honours Thesis, University of Melbourne.
- Gosz, J.R., Likens G.E., and Bormann, F.H. 1972. Nutrient content of litter fall on the Hubbard Brook experimental forest, New Hampshire. *Ecology* 53, 769-784.
- Graesser, A. 1980. *Diel Density Patterns of the Rock and Drift Fauna of the Toorong River, near Noojee*. B.Sc. Honours Thesis, Monash University.
- Hay, D.A. and Ball, I.R. 1979. Contributions to the biology of freshwater planarians (Turbellaria) from the Victorian Alps, Australia. *Hydrobiologia* 62, 137-164.
- Hay, J.E. 1977. *A Survey of the Invertebrate Fauna of Mt. Wellington Streams*. B.Sc. Honours Thesis, University of Tasmania.
- Howard, T.M. 1973. Studies in the ecology of *Nothofagus cunninghamii* Oerstr. II. Phenology. *Aust. J. Bot.* 21, 79-90.
- Hynes, H.B.N. 1970. *The Ecology of Running Waters*. Liverpool University Press, Liverpool.

- Hynes, H.B.N. 1975. The stream and its valley. *Verh. Int. Verein. theor. angew. Limnol.* **19**, 1-15.
- Hynes, H.B.N. 1976. Biology of Plecoptera. *Ann. Rev. Entomol.* **21**, 135-153.
- Hynes, H.B.N. and Hynes, M.E. 1975. The life histories of many of the stoneflies (Plecoptera) of south-eastern mainland Australia. *Aust. J. Mar. Freshwater Res.* **26**, 113-153.
- Illies, J. 1961. Versuch einer allgemeinen biozonotischen Gliederung der Fließgewässer. *Int. Revue. ges. Hydrobiol.* **46**, 205-213.
- Illies, J. and Botosaneanu, L. 1963. Problèmes et méthodes de la classification et de la zonation écologique des eaux courantes, considérées surtout du point de vue faunistique. *Mitt. int. Verein. theor. angew. Limnol.* **12**, 1-57.
- Jeffree, R.A. and Williams, N.J. 1980. Mining pollution and the diet of the purple-striped gudgeon *Mogurnda mogurnda* Richardson (Eleotridae) in the Finnis River, Northern Territory, Australia. *Ecol. Monogr.* **50**, 457-485.
- Knott, B. 1971. *Studies on some Tasmanian Phreaticolids*. B.Sc. Honours Thesis, University of Tasmania, Hobart.
- Knott, B., Suter, P.J. and Richardson, A.M.M. 1978. A preliminary observation on the littoral rock fauna of Hartz Lake and Hartz Creek, southern Tasmania, with notes on the water chemistry of some neighbouring lakes. *Aust. J. Mar. Freshwater Res.* **29**, 703-715.
- Korboot, K. 1963. Biological studies of some caddis flies (Trichoptera) from south east Queensland. *Univ. Qld. Pap. Dept. Entomol.* **1**, 241-274.
- Lake, P.S. 1978. On the conservation of rivers in Australia. *Aust. Soc. Limnol. Newsl.* **16**(2), 24-28.
- Lake, P.S. 1980. Conservation. In *An Ecological Basis for Water Resource Management* (Ed. W.D. Williams) pp. 163-173. Australian National University Press, Canberra.
- Lake, P.S. and Fulton, W. 1981. Observations on the freshwater fish of a small Tasmanian coastal stream. *Pap. Proc. Roy. Soc. Tas.* **115**, 163-172.
- Lake, P.S., Coleman, D., Mills, B. and Norris, R. 1977. A reconnaissance of pollution of the King River in the Comstock-Crotty area, West Tasmania. In *Landscape and Man* (Eds J. Kirkpatrick and M. Banks) pp. 81-100. Royal Society of Tasmania, Hobart.
- Landa, V. 1968. Developmental cycles of central European Ephemeroptera and their interrelations. *Acta. Entomol. Bohemoslov.* **65**, 276-284.
- Mackay, R.J. 1969. Aquatic insect communities of a small stream near Mont St. Hilaire, Quebec. *J. Fish. Res. Bd Canada.* **26**, 1157-1183.
- Mackay, R.J. and Kalff, J. 1969. Seasonal variation in standing crop and species diversity of insect communities in a small Quebec stream. *Ecology* **50**, 101-109.
- McMichael, D.F. 1952. *An Ecological Study of Warrah Creek, Warrah Sanctuary, N.S.W.* B.Sc. Honours Thesis, University of Sydney.
- Macmillan, L.A. 1975. *Longitudinal Zonation of Benthic Invertebrates in the Acheron River, Victoria*. B.Sc. Honours Thesis, Monash University.
- Malipatil, M.B. and Blyth, J.D. 1982. A qualitative study of the macroinvertebrate fauna of the Thomson River and its major tributaries, Gippsland, Victoria. *Rep. Nat. Mus. Vic.* **1**, 1-95.
- Mann, K.H. 1975. Patterns of energy flow. In *River Ecology* (Ed B.A. Whitton) pp. 248-263. Blackwells Scientific Publications, Oxford.
- Melbourne and Metropolitan Board of Works. 1975. *Report on Environmental Study into Thomson Dam and Associated Works. Volume 1. Proposed Works and Aquatic Environment. Volume 2. Environmental Implications and Conclusions*, Melbourne and Metropolitan Board of Works, Melbourne, Victoria.
- Metzeling, L.H. 1977. *An Investigation of the Distribution of Aquatic Macroinvertebrates found in Sections of Streams Flowing Through Areas with Differing Amounts of Vegetation Cover*. B.Sc. Honours Thesis, Monash University.
- Minshall, G.W. 1968. Community dynamics of the benthic fauna in a woodland springbrook. *Hydrobiologia* **32**, 305-339.
- Minshall, G.W. 1978. Autotrophy in stream ecosystems. *Bioscience* **28**, 767-771.
- Morrissy, N.M. 1967. *The Ecology of Trout in South Australia*. Ph.D. Thesis, University of Adelaide.
- Morrissy, N.M. 1978. The past and present distribution of marron in Western Australia. *Fish. Res. Bull. West. Aust.* **22**, 1-38.
- Morrissy, N.M. 1979. Inland (non-estuarine) halocline formation in a West Australian river. *Aust. J. Mar. Freshwater Res.* **30**, 343-353.
- Norris, R.H. 1972. *Factors Influencing Community Structure in Two Stream Systems*. B.Sc. Honours Thesis, Australian National University.
- Norris, R.H. 1978. *The Ecological Effects of Mine Effluents on the South Esk River (North-east Tasmania)*. Ph.D. Thesis, University of Tasmania.

- O'Farrell, A.F. 1949. The Blue Hole Expedition 1949. A Short-term limnological study on the Gara River, New South Wales. *J. New England Univ. Coll. Sci.* **5**, 46-82.
- Pennak, R.W. 1971. Towards a classification of lotic habitats. *Hydrobiologia* **38**, 321-334.
- Pennak, R.W. 1979. The dilemma of stream classification. In *Classification, Inventory, and Analysis of Fish and Wildlife Habitat*. Biological Science Program, U.S. Fish and Wildlife Service, FWS OBS-78 76, 59-66.
- Petersen, R.C. and Cummins, K.W. 1974. Leaf pack processing in a woodland stream. *Freshwater Biol.* **4**, 343-368.
- Pidgeon, R.W.J. 1978. *Energy Flow in a Small Stream Community: an Evaluation of the Effects of Different Riparian Vegetation*. Ph.D. Thesis. University of New England.
- Pidgeon, R.W.J. and Cairns, S.C. 1981. Decomposition and colonisation by invertebrates of native and exotic leaf material in a small stream in New England (Australia). *Hydrobiologia* **77**, 113-127.
- Plowman, K.P. 1979. Litter and soil fauna of two Australian subtropical forests. *Aust. J. Ecol.* **4**, 87-104.
- Richardson, A.M. and Swain, R. 1978. *The Freshwater Invertebrates*. Lower Gordon River Scientific Survey No. 6. The Hydro-Electric Commission of Tasmania, Hobart.
- Robinson, D.P. 1977. *The Study of the Invertebrate Fauna of Three Mountain Streams in Relation to Type of Land Use in Each of the Three Stream Catchments*. B.Sc. Honours Thesis, Monash University.
- Rogers, R.W. and Westman, W.E. 1977. Seasonal nutrient dynamics of litter in a subtropical eucalypt forest, north Stradbroke Island. *Aust. J. Bot.* **25**, 47-58.
- Shelford, V.E. and Eddy, S. 1929. Methods for the study of stream communities. *Ecology* **10**, 383-392.
- Slobodchikoff, C.N. and Parrott, J.E. 1977. Seasonal diversity in aquatic insect communities in an all-year stream system. *Hydrobiologia* **52**, 143-151.
- Smith, B.J., Malcolm, H. and Morison, P. 1976. *Dartmouth Environmental Survey. Report of the Invertebrate Survey*, pp. 1-91. National Museum of Victoria and State Rivers and Water Supply Commission of Victoria, Melbourne.
- Smith, B.J., Malcolm, H.E. and Morison, P.B. 1977. Aquatic invertebrate fauna of the Mitta Mitta Valley, Victoria. *Vict. Nat.* **94**, 228-238.
- Smith, B.J., Malcolm, H.E. and Morison, B.P. 1978. Survey of the invertebrate fauna of the Mitta Mitta Valley. In *State Rivers and Water Supply Commission 1978. Dartmouth Dam Project: Report on the Environmental Studies for River Murray Commission*, pp. 1-91. State Rivers and Water Supply Commission of Victoria, Melbourne.
- Smith, J.A. and Dartnall, A.J. 1980. Boundary layer control by water pennies (Coleoptera: Psephenidae). *Aquatic Insects* **2**, 65-72.
- Smith, M.J. and Williams, W.D. 1980. Reproductive strategies of some freshwater amphipods in southern Australia. In *Program, Abstracts, Participants. International Conference on Biology and Evolution of Crustacea, 19-23 May, 1980*. pp. 80. The Australian Museum, Sydney, Australia.
- Spain, A.V. 1973. Litter fall in a New South Wales conifer forest: a multivariate comparison of plan nutrient element status and return in four species. *J. appl. Ecol.* **10**, 527-556.
- Stout, J. and Vandermeer, J. 1975. Comparisons of species richness for stream-inhabiting insects in tropical and mid-latitude. *Am. Nat.* **109**, 263-280.
- Suter, P.J. and Williams, W.D. 1977. Effects of a total solar eclipse on stream drift. *Aust. J. Mar. Freshwater Res.* **28**, 793-798.
- Suter, P.J. and Bishop, J.E. 1980. The effect of mesh size on the interpretation of the life history of two mayflies from South Australia. In *Advances in Ephemeroptera Biology* (Eds J.F. Flannagan and K.E. Marshall) pp. 381-403. Plenum Press, N.Y.
- Towns, D.R. 1981. Life histories of benthic invertebrates in a Kauri forest stream in northern New Zealand. *Aust. J. Mar. Freshwater Res.* **32**, 191-212.
- Vannote, R.L. and Sweeney, B.W. 1980. Geographic analysis of thermal equilibria: a conceptual model for evaluating the effect of natural and modified thermal regimes on aquatic insect communities. *Am. Nat.* **115**, 667-695.
- Walker, T.M. 1972. *A Study of the Morphology, Taxonomy, Biology and Some Aspects of the Ecology of Paratya australiensis Kemp for Tasmania*. B.Sc. Honours Thesis, University of Tasmania.
- Waterhouse, J.H. 1980. Observations on the biology and ecology of two species of *Tasmanoperla* (Plecoptera). (Abstract of Honours thesis, University of Tasmania 1979). *Aust. Soc. Limnol. Newsl.* **18(2)**, 18-19.

- White, R.W.G., Swain, R. Coleman, D. and Hortle, M.E. 1980. Heavy metal pollution and the fauna of the King River. *Aust. Soc. Limnol. Newsl.* **18**(1), 16.
- Williams, W.D. 1976. Some problems for Australian limnologists. *Search* **7**, 187-190.
- Williams, W.D. 1977. Some aspects of the ecology of *Paratya australiensis* (Crustacea: Decapoda: Atiyidae). *Aust. J. Mar. Freshwater Res.* **28**, 403-415.
- Williams, W.D. 1980. Distinctive features of Australian Water Resources. In *An Ecological Basis for Water Resource Management* (Ed. W.D. Williams) pp. 6-11. Australian National University Press, Canberra.
- Williams, W.D. and Wan, H.F. 1972. Some distinctive features of Australian inland waters. *Water Res.* **6**, 829-836.
- Winterbourn, M.J. 1978. The macroinvertebrate fauna of a New Zealand forest stream. *N.Z. J. Zool.* **5**, 157-169.
- Winterbourn, M.J. 1980. The freshwater insects of Australasia and their affinities. *Paleogeogr., Paleoclimatol., Palaeoecol.*, **31**, 235-249.
- Yule, C.M. 1978. *Fauna-substrate Relationships in a Victorian Coastal Stream, with Consideration of the Impact of Dam Construction*. B.Sc. Honours Thesis, Monash University.
- Zwick, P. 1977. Australian Blephariceridae (Diptera). *Aust. J. Zool., Suppl. Ser. No.* **46**, 1-121.

Observations on the Food of Rainbow Trout, *Salmo gairdneri* Richardson, in Lake Purrumbete, Victoria.

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The stomach contents of rainbow trout taken from Lake Purrumbete at 3-monthly intervals between July 1976 and July 1977 contained a wide range of food types, particularly fish, Amphipoda, Cladocera, Diptera, Trichoptera, Hemiptera, Coleoptera and Gastropoda. Other food types eaten were Copepoda, Decapoda, Ostracoda, Isopoda, Odonata, Ephemeroptera, Hymenoptera, Lepidoptera, Hydracarina, Bivalvia and Gordiidae. Fish, mainly *Galaxias maculatus*, appear to be less abundant in the stomach contents of trout in Lake Purrumbete now than they were in 1967.

I. INTRODUCTION

In this paper we record the stomach contents of rainbow trout, *Salmo gairdneri* Richardson, taken during a study of the food and growth of chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), in Lake Purrumbete, Victoria, and discuss the significance of the occurrence of galaxiids in the diet of trout taken in the lake. Tilzey (1977) has recently reviewed studies on the food and growth of trout in Australia.

II. MATERIALS AND METHODS

The rainbow trout examined in this study were obtained from Lake Purrumbete in south-western Victoria at 3-monthly intervals between July 1976 and July 1977. Details of physicochemical parameters, phytoplankton, limnetic zooplankton, benthos and the macrofauna of the littoral weed beds and rocky areas of Lake Purrumbete are given by Timms (1973, 1976). Butcher (1947) and Cadwallader and Eden (1981) have commented on the fish fauna of the lake, with particular reference to chinook salmon. The methods employed in the present study are essentially those described by Cadwallader and Eden (1981). All but 14 of the 170 rainbow trout examined were taken by means of fleets of up to 12 gill nets of stretched mesh size ranging from 63 to 152 mm; the remaining 14 fish, all of which were taken in October 1976, were obtained by trolling with a variety of natural and artificial lures.

Fish were measured and weighed when fresh and their stomachs and contents were removed, wrapped in cheesecloth, and preserved in 10% formalin, together with any regurgitated material taken from the mouth and oesophagus. Food items were sorted in water in a petri dish under a low-power microscope and the diet of the trout in each sample was assessed by the numerical method (Hyslop 1980) and the ranking method of Pollard (1973). Preliminary analysis of the stomach contents of trolled and netted trout taken in October 1976 indicated that there were no significant differences in the diets of the two groups, so they were grouped together for subsequent analyses.

III. RESULTS

Details of the rainbow trout from which stomachs were obtained are given in Table 1. The major food types recorded in the stomachs are listed in Table 2.

With the exception of seven pigmy perch *Nannoperca australis* (Günther) taken in July

Table 1. Number of stomachs examined (N) and the length to caudal fork (LCF) and weight ranges of the rainbow trout from which they were obtained (E = empty stomachs).

Date	N	E	LCF range (mm)	Weight range (kg)
26-28 July 1976	62	12	230-690	0.20-5.40
24-26 October 1976	49	0	265-725	0.25-6.60
24-27 January 1977	21	3	325-690	0.44-4.00
26-28 April 1977	8	0	420-665	1.09-3.50
25-26 July 1977	30	6	350-660	0.50-4.20

1977, all the fish eaten were common galaxiids *Galaxias maculatus* (Jenyns).

Amphipods, including Gammaridae and, particularly, *Austrochiltonia* (Ceinidae), were sometimes taken in large numbers and usually formed a substantial part of the diet. *Daphnia* (Cladocera) were taken in large numbers and formed a major part of the diet only in spring (October), when they are abundant in Lake Purrumbete (Timms 1973). Other crustaceans eaten were cyclopoid copepods, the atyid shrimp *Paratya australiensis* Kemp (Decapoda), ostracods, and isopods of the genus *Heterias* (Asellata).

Insects eaten included members of the dipteran families Chironomidae, Syrphidae, Tipulidae, Ceratopogonidae, Stratiomyidae and Sciaridae, which were usually taken as larvae, although large numbers of pupae of *Procladius villosimanus* Kieffer and *Dicrotendipes* (Chironomidae) were also eaten. Other chironomids taken were *Chironomus duplex* Walker and *Ablabesmyia*. Trichopterans eaten included Hydropsychidae and, mainly, larvae of the leptocerid genus *Ocetis*. Corixidae (*Sigara*, *Micronecta*) and Notonectidae (*Anisops*) were the most common hemipterans in the diet; others eaten were members of the Pleidae, Gerridae, Pentatomidae and Psyllidae. Both adult and larval aquatic coleopterans were eaten, as well as some terrestrial forms. Those coleopteran families represented in the diet were Dytiscidae, Hydrophilidae (*Berosus*, *Hydrophilus*, *Sternophilus*), Carabidae, Scarabaeidae, Elateridae, Staphylinidae and Curculionidae. Odonata taken were mainly nymphs of the families Coenagrionidae, Aeshnidae, Synthemidae and Corduliidae. Other insects formed an insignificant part of the diet; they included an adult plecopteran of the genus *Dinotoperla* (Gripopterygidae), an ephemeropteran nymph, Hymenoptera (one individual of each of the families Formicidae, Apidae and Chalcidoidea) and a larval and adult lepidopteran.

Hydracarina (Arachnida) formed a significant part of the diet only in spring. The gastropods *Isidorella hainesii* (Tryon) (Planorbidae) and *Potomopyrgus niger* (Quoy and Gaimard) (Hydrobiidae) were the most common molluscs in the diet; others taken were *Gyraulus meridionalis* (Brazier) (Planorbidae) and the bivalve *Sphaerium*. Oligochaete and gordiid worms formed an insignificant part of the diet.

Algae and plant material were often found in the stomach contents, sometimes in large amounts. Parasitic acanthocephalans were found in the stomachs of fish taken in October 1976 (38 acanthocephalans in 6 stomachs) and January 1977 (1 acanthocephalan in 1 stomach).

IV. DISCUSSION

The rainbow trout fishery in Lake Purrumbete has been very successful, producing some extremely large fish. Wharton (1967) reported yearling trout from the lake weighing 3 lb (1.4 kg), 2.5-year-olds weighing 13 lb (5.9 kg), 3-year-olds weighing 18 lb 9 oz (8.4 kg) and 4-year-olds weighing 20 lb 8 oz (9.3 kg); these growth rates were considered world records for rainbow trout at the time (up to 1958). Trout are

Table 2. Number (N) of food organisms in the stomachs and the percentage composition (%) of the diet, as assessed by the ranking method, of rainbow trout taken in Lake Purrrumbete between July 1976 and July 1977.

Food type	July 1976		October 1976		January 1977		April 1977		July 1977	
	N	%	N	%	N	%	N	%	N	%
Vertebrata										
Pisces	210	22.7	38	3.0	2	2.8	80	30.0	23	18.7
Crustacea										
Amphipoda	22000	15.7	3410	9.5	1174	20.1	2022	17.8	3645	28.1
Cladocera			84500	20.0	53	3.9				
Copepoda			5	0.2						
Decapoda	20	3.9	2	0.9					1	1.7
Ostracoda			62	1.5						
Isopoda			33	0.4						
Insecta										
Diptera	11	2.7	23300	14.6	7	5.0			6	6.0
Trichoptera	1069	23.2	792	9.8	37	11.2	3	4.3	8	9.4
Hemiptera	14	2.5	48	3.8	1457	22.7	45	17.4	155	21.8
Coleoptera	4	1.5	65	7.4	33	9.0	1	2.2	1	1.2
Odonata	10	4.9	16	3.0	15	8.2				
Plecoptera			2	0.3						
Ephemeroptera					1	1.1				
Hymenoptera			2	0.3	1	0.8				
Lepidoptera	1	0.7			1	1.4				
Arachnida										
Hydracarina	5	0.6	1189	9.1	19	1.1				3.1
Mollusca										
Gastropoda	367	8.3	802	8.0	4	2.8	1192	15.7	405	3.4
Bivalvia	3	0.4	3	0.6						
Annelida										
Oligochaeta									3	1.4
Nematomorpha										
Gordiida	1	0.2							1	1.0
Algae/plant material	-	12.8	-	7.7	-	10.0	-	12.6	-	4.4

* = approximation only

opportunistic predators and usually select the largest and most readily accessible prey (Tilzey 1977). The phenomenal growth rate in Lake Purrrumbete in the past reflects an excellent food supply, but such a growth rate no longer occurs in the lake and there is evidence to suggest that this may be attributable to the reduced availability of forage fish, particularly *G. maculatus*.

A field examination of the stomach contents of 28 rainbow trout gill-netted from Lake Purrrumbete in April 1967 revealed that galaxiids formed a substantial part of the diet of the trout (unpublished data of B.R. Tunbridge, Fisheries and Wildlife Division). A total of 708 galaxiids was recorded from the 28 trout (mean of 25 per stomach; range 12-47), whose LCF range was 359-620 mm and whose weight range was 0.86-4.4 kg. Unfortunately, during April 1977 only 8 rainbow trout were taken. These fish (which had similar length and weight ranges to the trout taken in 1967 — Table 1) had eaten 80 galaxiids (mean of 10 per stomach; range 1-25), which made up 30% of the stomach contents for the April 1977 sample (Table 2). Although the number of trout in the April 1977 sample was small, these figures nevertheless suggest that galaxiids were less common in the diet of the rainbow trout in Lake Purrrumbete in 1977 than they were in 1967, and suggest that perhaps the abundance and/or availability of galaxiids in the lake

Table 3. Numbers (N) of rainbow trout released in Lake Purrumbete between 1958 and 1977. Compiled from Fisheries and Wildlife Division records and Wharton (1969).

Year	N(thousands)	Year	N(thousands)
1958	0	1968	0
1959	11.5	1969	10.5
1960	18.0	1970	73.5
1961	89.1	1971	83.3
1962	39.6	1972	72.6
1963	0	1973	72.0
1964	0	1974	56.1
1965	9.3	1975	72.0
1966	11.3	1976	50.0
1967	0	1977	0

has been reduced. Certainly, anecdotal reports (from anglers and local residents) suggest that *G. maculatus* is much less abundant in Lake Purrumbete at present than formerly.

As well as forming a large part of the diet of rainbow trout in Lake Purrumbete, *G. maculatus* also forms a large part of the diet of chinook salmon in the lake (Cadwallader and Eden 1981). Figures before 1958 are incomplete, but since 1959 rainbow trout have been released regularly, sometimes in large numbers (Table 3); during the same period, chinook salmon were released in 1958 ($n = 62,000$), 1964 (42,000) and 1967 (19,300) and then liberations did not occur again until 1976, when 15,000 were released. Predation by these salmonids on *G. maculatus* most probably affected the abundance of galaxiids in Lake Purrumbete. Stocking densities of trout in the past (Table 3, 1958-1967) were generally less than in recent years (1969-1976), so that growth rates and the number of galaxiids per trout stomach may well be directly related to differences in stocking density, both being affected by the number of salmonids present at a given time. Several authors in both Australia and New Zealand, e.g. Fletcher (1919), Armstrong (1935), Fish (1966) and Frankenberg (1966), have commented on the apparent elimination or reduction in abundance of lake-dwelling galaxiids following the introduction of trout. Neither rainbow trout nor chinook salmon reproduce in Lake Purrumbete, their numbers depending solely on releases of hatchery-produced fish. Under these circumstances introduced salmonids are unlikely to eliminate the galaxiids from the lake unless the lake is grossly mis-managed by overstocking with trout or salmon or both.

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Armstrong, J.S. 1935. Notes on the biology of Lake Taupo. *Trans. R. Soc. N.Z.* 65, 88-94.

Butcher, A.D. 1947. Quinnet salmon in Victorian inland waters. *Victoria Fish. Game Dept. Fish. Pamphl.* No. 4, 1-28.

Cadwallader, P.L. and Eden, A.K. 1981. Food and growth of hatchery-produced chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), in landlocked Lake Purrumbete, Victoria, Australia. *J. Fish Biol.* 18, 321-330.

- Fish, G.R. 1966. An artificially maintained trout population in a Northland lake. *N.Z. J. Sci.* **9**, 200-210.
- Fletcher, H.J. 1919. Lake Taupo and its trout. *N.Z. J. Sci. Technol* **2**, 367-370.
- Frankenberg, R. 1966. Fishes of the family Galaxiidae. *Aust. Nat. Hist.* **15**, 161-164.
- Hyslop, E.J. 1980. Stomach contents analysis — a review of methods and their application. *J. Fish Biol.* **17**, 411-429.
- Pollard, D.A. 1973. The biology of a landlocked form of the normally catadromous salmoniform fish *Galaxias maculatus* (Jenyns) V. Composition of the diet. *Aust. J. Mar. Freshwater Res.* **24**, 281-295.
- Tilzey, R.D.J. 1977. Key factors in the establishment and success of trout in Australia. *Proc. Ecol. Soc. Aust.* **10**, 97-105.
- Timms, B.V. 1973. *A Comparative Study of the Limnology of Three Maar Lakes in Western Victoria*. Ph.D. thesis, Monash University.
- Timms, B.V. 1976. A comparative study of the limnology of three maar lakes in western Victoria I. Physiography and physicochemical features. *Aust. J. Mar. Freshwater Res.* **27**, 35-60.
- Wharton, J.C.F. 1967. Natural resources of the Corangamite region; future of fish and wildlife in the region. *Vic. Res.* **9** (2), 51-53.
- Wharton, J.C.F. 1969. Trout liberations in Victorian streams and lakes from 1958 to 1967. *Victoria Fish. Wildl. Dept. Fish. Circ.* **19**, 1-357.

Notes on the Distribution and Life Cycle of *Paranaspides lacustris* Smith (Crustacea: Syncarida)

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New information on the distribution and life history of *Paranaspides lacustris* is provided and discussed.

I. DISTRIBUTION

Since the original descriptions of the Great Lake shrimp *Paranaspides lacustris* early this century (Smith 1908, 1909a, b) several authors have commented on the variation in abundance of this syncarid (Manton 1930; Tillyard 1933; Evans 1942; Nicholls 1947; Williams 1965, 1974; Lake and Knott 1973). The known distribution of the species has previously been established as Great Lake and two artificial waters below this system, Shannon Lagoon and Penstock Lagoon (Williams 1965). Within these areas it has been noted that the species is found only in association with patches of aquatic vegetation (Lake and Knott 1973) and that it has a depth range of 1.0 to 8.1 m (Williams 1965).

My observations of this species, which include collections by FBA net, electro-shocker, boat towed dredge and Ekman grab, suggest that the depth range is appropriate with only minor extensions to 0.2 - 10.0 m. However, it is usually only taken in significant numbers in shallow water when the water level is low (in Great Lake at least). This brings those areas where aquatic vegetation (*Nitella* sp. in Great Lake) survives into shallow waters. The constant raising and lowering of the water level in this lake prevents the development of littoral vegetation and consequently shoreline fauna of any variety is sparse.

Following collection of two specimens of *P. lacustris* in the Lake River below the Woods Lake dam, further collections were made in Arthurs Lake and Woods Lake in June and July 1977 (Fig. 1). Woods Lake appears to support a large population of this species.

The distribution of *P. lacustris* parallels the distribution of the native fish genus *Paragalaxias* (McDowall & Fulton 1978) where two species occur in Great Lake and a third is found in Arthurs and Woods Lakes. Studies of the benthic macro-fauna of Great Lake and Arthurs Lake also show marked similarities (Fulton, unpublished). The present natural drainage of the two lake systems is towards opposite ends of the state (see Fig. 1) but the separation of Great Lake and Arthurs Lake is only 6 km horizontally with a height difference of 81 m.

II. LIFE HISTORY

The life cycle of the species was speculated upon by Williams (1965) who suggested that it may be similar to that of *Anaspides tasmaniae* in which hatching takes place between June and September and egg laying during October and November (Hickman 1937). Hatching of *P. lacustris* may occur during June, at least, as a specimen measuring 2.0 mm collected by the author on 6 June 1975 from Great Lake had probably only recently hatched. The size is similar to that recorded by Hickman (1937) for newly hatched *A. tasmaniae*.



Fig. 1. Sites of recent collections of *Paranaspides lacustris*.

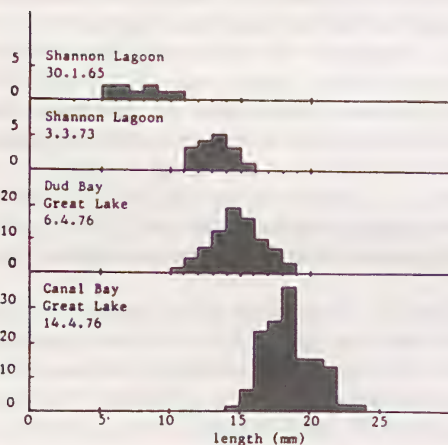


Fig. 2. Length frequency analysis of available samples of *Paranaspides lacustris* (length was measured from tip of rostrum to end of telson).

The largest specimen I have collected (female, 4 November 1975, Canal Bay, Great Lake) measured about 25 mm. All specimens collected at any one time appear to have belonged to a single year class. Although overlapping year classes could have occurred from June to November they may have been missed as *P. lacustris* only grows to about 10 mm during this time, and was probably at least semi-planktonic for part of this time. The life cycle appears, therefore, to last no more than 18 months with hatching probably taking a further 6-8 months. Length frequency analysis of available samples is given in Fig. 2.

The diet of *P. lacustris* as indicated by Manton (1930) and Williams (1965): diatoms, slime, fine detritus, algal filaments, fungal hyphae, would appear to be consistent with

aquarium observations that *P. lacustris* spends most of its time moving on aquatic plant stems and appears to be grazing upon these plants with its peraeopods.

III. CONCLUSIONS

If the suggested univoltine life cycle proves to be correct then this species would be extremely vulnerable to habitat alteration as the failure of one breeding year could effectively eliminate the species. *P. lacustris* has so far survived major water level changes in Great Lake although temporary population reductions have followed each change. However, with each additional elevation of the lake the potential fluctuations in water level become greater. It is proposed to add a further 9 m to the Miena dam in the near future. This is about 3 m more than the original maximum depth and an increase of about 50% to the present maximum depth.

On the positive side, the modifications to Great Lake should relieve some of the present riparian demands from Woods Lake, giving rise to more natural conditions in that lake and so protecting the population of *P. lacustris*. Arthurs Lake, Penstock Lagoon and Shannon Lagoon should continue as at present.

- Evans, J.W. 1942. *The Food of Trout in Tasmania*. Salmon and Freshwater Commission, Hobart.
- Hickman, V.V. 1937. The embryology of the syncarid crustacean, *Anaspides tasmaniae*. *Pap. Proc. Roy. Soc. Tas.* 1936, 1-35.
- Lake, P.S. and Knott, B.K. 1973. On the freshwater crustaceans of the Central Plateau. In: *The Lake Country of Tasmania*. (Ed. M.R. Banks) pp 95-99. Royal Society of Tasmania, Hobart.
- Manton, S.M. 1930. Notes on the habits and feeding mechanisms of *Anaspides* and *Paranaspides* (Crustacea, Syncarida). *Proc. Zool. Soc. Lond.* 1930, 791-800.
- McDowall, R.M. and Fulton, W. 1978. A revision of the genus *Paragalaxias* Scott (Salmoniformes: Galaxiidae). *Aust. J. Mar. Freshwater Res.* 29, 93-108.
- Nicholls, G.E. 1947. On the Tasmanian Syncarida. *Rec. Queen Vict. Mus.* 2, 9-16.
- Smith, G.W. 1908. Preliminary account of the habits and structure of the Anaspididae, with remarks on some other freshwater Crustacea from Tasmania. *Proc. Roy. Soc. Ser. B.* 80, 465-473.
- Smith, G.W. 1909a. The freshwater Crustacea of Tasmania, with remarks on their geographical distribution. *Trans. Linn. Soc. Lond. (Zool.)* 11, 61-92.
- Smith, G.W. 1909b. On the Anaspidacea, living and fossil. *Quart. J. micr. Sci.* 53, 489-578.
- Tillyard, R.J. 1933. *Report of the Fisheries Commissioners for the Year ending June 30th, 1933*. Hobart.
- Williams, W.D. 1965. Ecological notes on Tasmanian Syncarida (Crustacea: Malacostraca), with a description of a new species of *Anaspides*. *Int. Revue ges. Hydrobiol.* 50, 95-126.
- Williams, W.D. 1974. Freshwater Crustacea. In *Biogeography and Ecology in Tasmania*. (Ed. W.D. Williams) pp 63-112. (*Monogr. Biol.* 25). Junk, The Hague.

Techniques for Collecting and Culturing Eggs of Two Sleepy Cod Species in the Genus *Oxyeleotris* (Perciformes: Eleotridae)

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Preliminary observations of the sexual dimorphism, eggs and early development of two *Oxyeleotris* species are presented. The development of spawning traps is traced and culture of harvested eggs to the feeding stage is described. Future refinements of the spawning traps, tank culture systems and larval food production are briefly discussed.

I. INTRODUCTION

Oxyeleotris lineolatus (Steindachner 1867) and the second species, *Oxyeleotris* sp., are among the largest of freshwater eleotrids native to Australia. Although known to be sympatric in many areas the details of the range of each of these eleotrids have yet to be determined; however, the total range includes most of the North-east Coast drainage division — from the Fitzroy River system northwards — as well as the Gulf of Carpentaria and Timor Sea divisions (Lake 1978).

These species have several characteristics important from a recreational fishery point of view; they regularly grow to a weight exceeding 1 kg, will breed in impoundments, are easily captured and excellent to eat (Lake 1971, 1978).

Despite potential and increasing interest in recent years the only information published, which refers to *O. lineolatus*, is that provided by Lake (1971, 1978). In 1971 as part of a stocking programme, sleepy cod traps were developed. Observations on adults and eggs found in these traps and subsequent attempts at limited culture are summarised below.

II. MATERIALS AND METHODS

The first traps were constructed from 55 l metal oil drums. The inside surface of each drum was blackened by burning, both ends were perforated and one was detached to form a hinged lid, which could be closed prior to removal of the trap from water. Traps, set in the Dawson River (central eastern Queensland), were usually placed at a depth of 1.0 m; they were suspended horizontally by a wire brace with the lid wide open.

Following the discovery of egg patches on the ceilings of these traps, removable sliding plywood panels were incorporated as ceiling laying substrates. During late 1979 and early 1980, open ended 55 l drums (Fig. 1) were fully lined with thin resistant laminate sheeting; this lining could be removed at will and small pieces, to which egg patches adhered, cut out to be held for culture. The culture system comprised aquaria (with individual water filtration units fitted) into which the egg patch substrate panels were placed at an angle; the eggs on the shaded lower surface of the panel were agitated by a bubble stream from an aerator outlet under the panel.

III. RESULTS

On 19 October 1971 a pair of *O. lineolatus* were captured in a drum which also contained a newly laid egg patch; the drum was set in the Dawson River. The female was 381 mm long (TL) and weighed 792 g, the male measured 432 mm and weighed 1302 g.

The individuals were easily sexed by the dimorphic urogenital papillae; that of the female being longer and fatter than the male (Fig. 2). The egg patch was roughly circular and 0.2 m in diameter. The fertile eggs were light straw-coloured fusiform tear drops 1.0 mm in diameter and 2.0 — 2.5 mm in length. The chorion was clear and the yolk of early stages always toward the broad outer end of the egg; the head of the developing larva was always toward the narrow tapered end of the egg which was attached to the substrate by a short adhesive thread (Fig. 3).

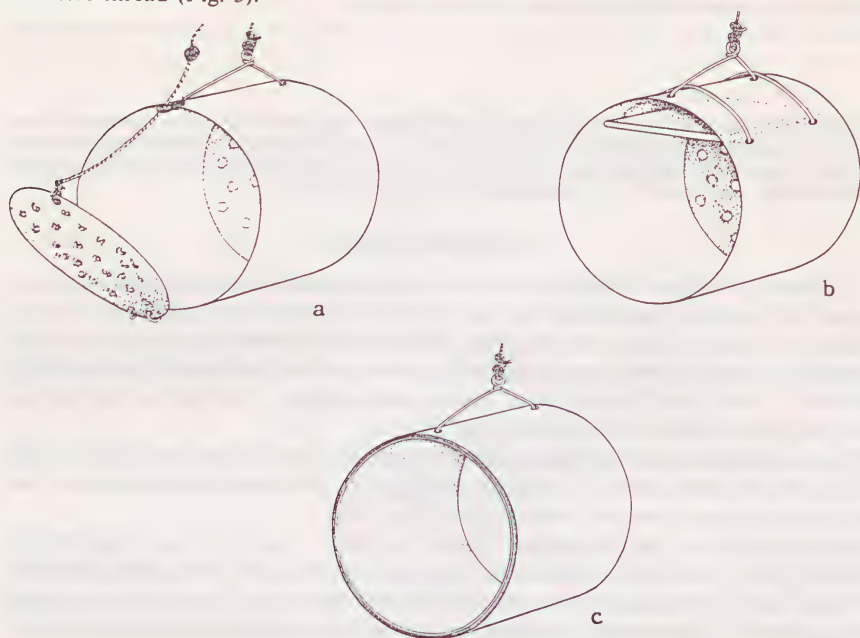


Fig. 1. Sleepy cod traps. (a) Initial adult trap. (b) Refined egg trap. (c) Laminate lined open egg trap.

In subsequent seasons the following observations were made. Firstly, traps set at other depths between the surface and 3.0 m were not as heavily utilized as those set at 1.0 m. Spawning occurred from October to February continuously, including periods of rising water levels immediately prior to a flood peak. Dawson River *O. lineolatus* displayed a preference for laying on the ceilings of traps — egg patches were seldom found on other parts of the drums. In contrast, although both *Oxyeleotris* species inhabit the Timor Sea drainage division (D. Hoese, Australian Museum, personal communication) eggs were laid all over the inside drum surface — except the ceiling. Naturally laid egg patches ranged in size from 0.08 to 0.7 m² in area containing from 5,000 to 70,000 eggs (35-100 cm⁻²); however, most patches were 0.3 — 0.4 m². Whilst a wide size range of adults was captured in traps, the smallest mature individuals were about 250 mm in length. Large size differences between individuals of pairs were frequently noted; the male was usually larger and up to twice the size of the female.

Artificial fertilization was possible by sacrificing two mature adults. Oocytes from dissected ovaries were painted on to plywood; white milt, from a dissected testis, was mixed with water and washed over the oocyte layer, or the egg panel was immersed in a milt-water mixture for 5-10 min.

Once laid, the hatching time of the eggs varied from 5 to 7 days; larvae were unable to survive more than several days without food.

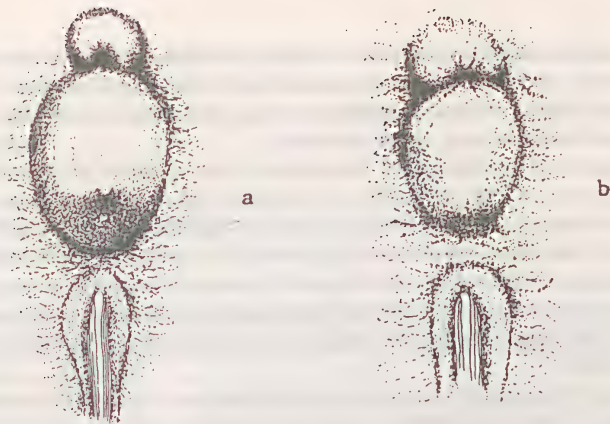


Fig. 2. Sexual dimorphism in *O. lineolatus*. (a) Enlarged urogenital papilla of mature female. (b) Urogenital papilla of mature male.

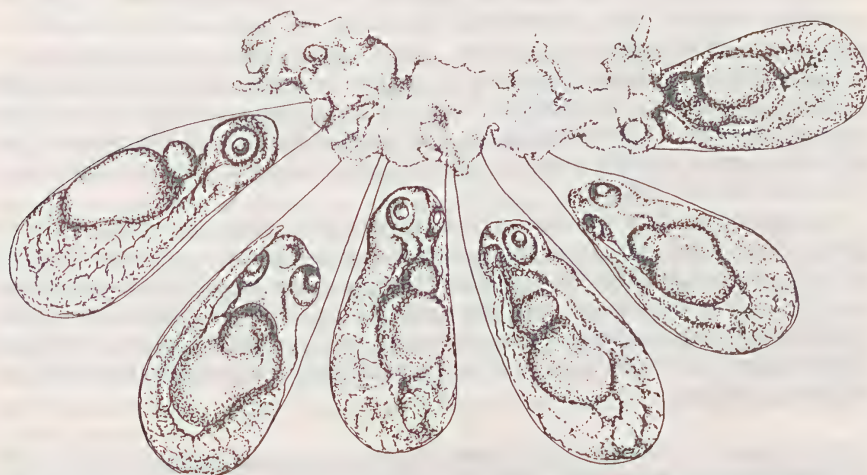


Fig. 3. Cluster of developing eggs of *O. lineolatus* showing chorionic shape and larval orientation.

IV. DISCUSSION

Sexual dimorphism in body and fin morphometrics and coloration has been reported for a number of eleotrids (Breder and Rosen 1966; Sterba 1973; Auty 1978). However, the only other species reported to exhibit the urogenital papilla difference described in this paper is *Oxyeleotris marmorata* (Tan and Lam 1973). The size difference noted between males and females could be partially explained by faster growth in males as reported in *O. marmorata* (Tay and Seow 1974). Larger males are also typical for another eleotrid genus, *Hypseleotris* (Auty 1978).

Whilst it is not possible to explain the heavier utilization of laying sites at 1.0 m, it is relevant to note that at this depth the eggs would be insulated from surface temperature extremes, at a level unlikely to become deficient in oxygen and safe from dessication by exposure due to minor stream level fluctuations.

Observations suggest that one or both parents remain to guard the eggs after laying. It is presumed, therefore that only one pair uses one trap at a time. The removable or replaceable laying substrates enable the eggs of sequential spawnings, over a period of months in the same trap, to be harvested.

The observed preference of North-east Coast division *O. lineolatus* for laying in shaded areas on the underside of artificial substrates has been corroborated by subsequent observations of the distribution of eggs laid on natural substrates. In eastern streams *O. lineolatus* egg patches have been found on the undersides of rock ledges, roots and submerged hollow logs. It is suggested that the difference in laying sites in traps could reflect utilization by the two species and regional populations of different sites in the wild. An extended spawning season has also been reported for another Australian eleotrid (Auty 1978).

The egg structure and hatching times are similar to those of *O. marmorata* (Tan and Lam 1973). Up to 700,000 eggs have been collected and cultured to the feeding stage in one season. The sequential food preferences of larvae of these two species are unknown; however, studies on other eleotrids have indicated that early larvae will take very small nauplii and rotifers (Sterba 1973).

Planned refinements to the spawning traps are, firstly, to have open mesh, hinged lids to facilitate capture of the adults when egg patches are harvested and, secondly, to experiment with different lining materials. Future tank rearing systems will comprise 50-60 l aquaria in which egg patch panels will float with the eggs facing down. Filtration and aeration will be achieved by a variable flow pump system that creates water currents but eliminates streams of bubbles from tanks. After hatching the flow will be slowed and food organisms added. Suitable food will be provided by means of techniques outlined in Green and Merrick (1980).

The significance of the techniques described is that with a minimum of cheap and easily obtainable materials, acceptable manageable spawning sites can be provided which will be heavily utilized, enabling the harvesting of large numbers of eggs from the wild. These eggs can then be cultured in small tanks and, if food can be provided for the larvae, production of large numbers of these two useful and desirable species can be achieved without large hatchery facilities involving the maintenance of adult breeding stocks and extensive pondages.

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Auty, E.H. 1978. Reproductive behaviour and early development of the empire fish *Hypseleotris compressus* (Eleotridae) Aust. J. Mar. Freshwater Res. 29, 585-94.

Breder, C.M. and Rosen, D.E. 1966. *Modes of Reproduction in Fishes*. Natural History Press, New York.

Green, L.C. and Merrick, J.R. 1980. Tropical freshwater fish culture: a covered pond improves plankton and fry production. *Aquaculture* 19, 389-94.

Lake, J.S. 1971. *Freshwater Fishes and Rivers of Australia*. Nelson, Melbourne.

Lake, J.S. 1978. *Freshwater Fishes of Australia. An Illustrated Field Guide*. Nelson, Melbourne.

Steindachner, F. 1867. Über einige fische aus dem Fitzroy-Flusse bei Rockhampton in Ost-Australien. *Sitzungsb. K. Akad. Wiss. Wien* 55, 9-16.

Sterba, G. 1973. *Freshwater Fishes of the World. Vol. 2*. T.F.H. Publications, Hong Kong.

Tan, O.K.K. and Lam, T.J. 1973. Induced breeding and early development of the marble goby (*Oxyeleotris marmorata*, Blk.). *Aquaculture* 2, 411-23.

Tay, S.H. and Seow, P.C. 1974. Observations on the monoculture of induced bred *Oxyeleotris marmorata*, Bleeker (marble goby) in a pond at Sembawang. *Singapore J. Pri. Ind.* 2, 150-54.

The Relationships between Freshwater Fish Distribution, Stream Drainage Area and Stream Length in Some Streams of South-east Australia

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Relationships between the number of fish species in a stream and drainage basin area were examined using data from six Australian streams. Seven model relationships were tested for goodness of fit. Data on the number of fish species and stream length were analyzed in a similar way. For three unpolluted streams the best fit was provided by a power function between the number of fish species and either drainage basin area or stream length, with the former providing a better fit than stream length. For one permanent unpolluted stream the best fit was an exponential function between number of fish species and stream length with the best fit between number of fish species and drainage area being a power function. The same relationships did not apply for two streams subject to intermittent flow or heavy metal pollution. Species diversity (H) for the two unpolluted streams did not increase downstream significantly. The appropriateness of the concept of stream order to the distribution of fish is questioned.

I. INTRODUCTION

It is generally accepted that the number of fish species in natural streams increases downstream (e.g. Hynes 1970). Increasing species richness downstream has been related to depth (e.g. Sheldon 1968), gradient (e.g. Hocutt and Stauffer 1975), stream order (e.g. Kuehne 1962; Harrel *et al.* 1967; Whiteside and McNatt 1972) and area of drainage basin (Thompson and Hunt 1930; Larimore and Smith 1963). All of these parameters are in themselves functions of stream size and possible habitat diversity.

In terrestrial environments, the power function of the species-area relationship (Preston 1962; MacArthur and Wilson 1967) has been used as a model to examine the relationship between species richness and size or area of living space. In a recent review Connor and McCoy (1979) have critically examined the theoretical and statistical assumptions behind the species-area relationship and have pointed out some major failings in past and present work in this field. Nevertheless, if correct statistical procedures are followed, species-area relationships can be used to compare patterns of species richness.

In rivers the amount of living space for fish can be assumed to be a function of both stream volume and stream discharge. Within a river system, drainage area is directly proportional to mean annual discharge (Hack 1957; Gregory and Walling 1973):

$$Q_m = aA^b$$

Where A = drainage area, Q_m = mean annual discharge and a and b are constants. Leopold and Maddock (1953) showed that the width (W) and depth (D) increase with mean annual discharge.

$$W = K_1 Q_m^{C_1}$$

$$D = K_2 Q_m^{C_2}$$

with K_1 , C_1 , K_2 and C_2 being constants. Substitution of equation (2) or (3) separately into equation (1) leads to the conclusion both width and depth are proportional to drainage area.

Hack (1957), Gray (1961) and Smart and Surkan (1967) have shown that mainstream length (L) and drainage area (A) are related by the equation

$$L = CA^{n'}$$

where C and n' are constants ($n' = 0.5$).

Drainage basin area can thus be seen to be proportional to discharge and to stream volume.

For lentic environments Barbour and Brown (1974), Haas (1975) and Nilsson and Nilsson (1978) have reported a power function relationship between number of fish species and the surface area (not volume) of lakes. For streams in Illinois, Thompson and Hunt (1930) and Larimore and Smith (1963) reported that number of fish species in a stream was logarithmically proportional to the drainage basin area and in rivers of eastern coastal U.S.A: Sepkoski and Rex (1974) reported that the number of species of freshwater mussels was best predicted by drainage basin area.

In this paper the relationships between fish species richness(s) and drainage basin area and stream length are examined in six Australian streams. The relationship between fish species richness and stream order is also examined.

II. METHODS

Data on fish species distribution were obtained for five streams in Tasmania and one in Victoria (Table 1).

The number of fish species in each river was determined at a number of sampling stations and, for each sampling station, the drainage basin area was determined by planimetry from 1:50,000 maps. Numerical data suitable for calculation of fish species diversity were available for Parson's Bay Creek and Ironstone Creek.

The Brillouin diversity index (H) was calculated for each station:

$$H = \frac{1}{N} \log\left(\frac{N!}{n_1! n_2! \dots n_5!}\right)$$

where N = total number of individuals comprising n_i in each of five species ($i = 1, 2 \dots 5$) for example.

This index was chosen because it is an actual measurement of the diversity of samples collected (Pielou 1975; Kaesler *et al.* 1978) and can be used to give a satisfactory estimate of the diversity of discrete communities (Kaesler *et al.* 1978; Laxton 1978).

Table 1. Details of the streams and the number of fish species.

Name of stream	Source position	No. of native fish spp.	No. of introduced fish spp.	Status of stream	Data source
Parsons Bay Creek, Tasmania	43°11'S, 147°47'E	9	1	Permanent, unpolluted	Lake and Fulton 1982
Ironstone Creek, Tasmania	42°44'S, 147°38'E	5	1	Permanent, unpolluted	Tasmanian Inland Fisheries Commission
Coal River, Tasmania	43°30'S, 147°31'E	6	3	Permanent, unpolluted	Bennison 1975; Sloane 1976; P.S. Lake (unpubl.)
Seven Creeks, Victoria	36°52'S, 145°50'E	8	5	Permanent, unpolluted	Cadwallader 1979
Bagdad Rivulet, Tasmania	42°35'S, 147°15'E	3	3	Intermittent, unpolluted	Tasmanian Inland Fisheries Commission
South Esk River, Tasmania	41°27'S, 147°45'E	3	3	Permanent, polluted	R. Norris (unpubl.)

The number of fish species per site(s) for each stream was regressed against either drainage basin area (A) (in km^2), using a Hewlett-Packard HP9815A calculator. The same procedure was carried out for number of fish species per site and stream length (L) (in km). The coefficient of determination (r^2) was determined for each model and the F ratio value was used for testing the goodness of fit for the appropriate degrees of freedom.

Connor and McCoy (1970) in their review of the statistics of the species-area relationship point out that to test the goodness of fit of various regression models it is appropriate to use Model I regression method. In this study the independent variable, drainage basin area is subject to error and thus for accurate estimates of the variance of the regression parameters, Model II regression was used. The geometric mean estimate of the functional regression or the GM regression method described by Ricker (1973) was used for Model II regression.

III. RESULTS

For three of the permanent unpolluted stream systems, with a majority of native species, the best fit for the relationship between number of fish species per site and drainage basin area or stream length is provided by the power model (Table 2). The gradients b of the drainage area equations for these three streams are similar (0.5773, 0.4712, 0.4872), while values of b for the number of fish species in relation to stream length vary considerable. For all three creeks the power model relationship between number of fish species and drainage basin area has a better fit than the power model relationship between number of fish species and stream length.

For the Coal River, the best fit was an exponential model between number of fish species and stream length, with the next best relationship being a power model between number of fish species and drainage area. The reason why the relationships of best fit for the Coal River differ from those of the other three permanent unpolluted streams examined is unclear, but it may be related to the presence of a small weir on this river near its mouth to the sea.

Table 2. Results of the regression analyses of number of fish species on either area of the drainage basin or the stream length for three Australian streams.

Name of stream	Parameter tested	Model of best fit	F ratio and P	Model I regression	Model II regression	
				Coefficient of determination R	a	b
Parsons Bay Creek	Area	Power	358.00 $p < 0.005$	0.9728	0.1469	0.5773
	Length	Power	283.92 $p < 0.005$	0.9660	0.2618	1.1118
Ironstone Creek	Area	Power	14.74 $p < 0.025$	0.7865	0.1528	0.4712
	Length	Power	9.03 $p < 0.05$	0.6929	4.5820	0.4202
Seven Creeks	Area	Power	56.00 $p < 0.005$	0.7467	0.3837	0.4872
	Length	Power	44.33 $p < 0.005$	0.7000	0.4111	0.6078

The South Esk River is severely polluted by cadmium and zinc below its junction with Story's Creek which has mining activity in its catchment (Norris 1978). For nine sampling stations, which include some in the polluted section, the number of fish species is unrelated to drainage basin area. For the four sampling stations above the pollution, however, the power model provides the best fit between number of fish species and drainage basin area with a F ratio of 14.35, $P < 0.05$; ($r^2 = 0.8777$, $a = 0.0004$ and $b = 1.4289$). The relationship between number of fish species and stream length in the South Esk similarly breaks down with the advent of pollution.

For Bagdad Rivulet the model of best fit between number of fish species and drainage basin area was the linear model (F ratio = 13.56, $P < 0.01$, $r^2 = 0.7100$, $a = 0.4001$, $b = 0.0399$). For stream length the linear model was also the best fit (F ratio = 30.89, $P < 0.01$, $r^2 = 0.8606$, $a = -0.3747$ and $b = 0.2742$). Bagdad Rivulet differs from the first three streams in that it has a high proportion of introduced fish species (three out of six) and it ceases to flow in summer.

The values of H for fish collected at six sites at Parsons Bay Creek on both sampling occasions do not increase significantly downstream (May: $\chi^2 = 1.5309$ for 5 d.f., $P > 0.05$; December: $\chi^2 = 3.3285$ for 5 d.f., $P > 0.05$ (Table 3). In Ironstone Creek the values of H also do not increase significantly on a downstream direction ($\chi^2 = 0.083$ for 5 d.f., $P > 0.05$) (Table 4).

Table 3. H values for fish collected in Parsons Bay Creek in May and December 1976.

Site No.	Stream length km	Catchment area km ²	No. of species		H	
			May	Dec	May	Dec
1	2.4	1.6	1	1	0	0
2	5.2	9.3	3	2	1.1411	0.6168
3	7.6	20.8	4	4	1.5984	1.4771
4	9.5	25.8	5	5	1.4751	0.4940
5	12.3	35.4	5	6	1.3938	1.7137
6	12.6	36.0	6	6	1.5248	2.2403

Table 4. H values of fish collected in Ironstone Creek in January 1971.

Site No.	Stream length km	Catchment area km	No. of species	H
1	5.0	21.9	3	0.9196
2	10.2	55.1	4	1.4704
3	14.0	68.9	6	1.7799
4	17.6	72.0	5	1.9949
5	21.4	80.9	5	0.8152
6	23.9	89.2	5	1.1290

Parsons Bay Creek, following the stream order system of Horton (1945) as modified by Strahler (1957), is an order 2 stream while Sevens Creeks for the section sampled is an order 6 stream.

For Parsons Bay Creek the best fit between number of fish species and stream order is provided by the linear model with $r^2 = 0.7105$ and a F ratio of 24.5455 for 1 and 11 d.f., $P < 0.05$. For Seven Creeks the best fit is provided by the inverse linear model ("Linear [var.T]") ($1/S = a + b$ [stream order]) with $r^2 = 0.3953$ and the F ratio of 3.1422 for 1 and 5 d.f., $P < 0.1$. For both streams the fit between number of fish species and stream order for the regression models tested is considerably poorer than the fit between number of fish species and catchment area or number of fish species and stream length.

IV. DISCUSSION

As for relatively undisturbed streams elsewhere in the world, the number of fish species increased in a downstream direction in the undamaged streams examined in this study. Also the number of fish species increased by addition rather than replacement, a finding similar to that found, for example, in North America (Sheldon 1968; Hocutt and Stauffer 1975; Evans and Noble 1979).

Freshwater fish in terms of total abundance and consequently in number of total species may be expected to increase with an increase in the amount of living space. It is difficult to measure directly in any meaningful sense the amount of living space in a normal stream. It was suggested earlier that the amount of living space in a stream over an extended period of time may be directly proportional both to catchment area and to stream length. In the relatively undamaged streams examined in this study there is a significant relationship between the number of fish species in a stream and the catchment area with a power relationship being the most applicable.

In 1930 Thompson and Hunt, in analyzing the results of their extensive survey of fish in streams of Champaign County, Illinois, found that there was a logarithmic relationship between the number of fish species and the drainage area. This finding seems to have been neglected by fish biologists until, for the same streams, Larimore and Smith (1963) confirmed the findings of Thompson and Hunt (1930) when unpolluted streams were considered.

The data of Thompson and Hunt (1930) and Larimore and Smith (1963) were reexamined. For the data of Thompson and Hunt (1930) the model of best fit between number of fish species and drainage basin area was the logarithmic model ($F = 156.62$, $P < 0.005$, $r^2 = 0.9751$, $a = 2.1822$, $b = 2.2228$). For the data of Larimore and Smith (1963), the model of best fit is the power model ($F = 1230.87$, $P < 0.005$, $r^2 = 0.9976$, $a = 5.5720$, $b = 0.2210$).

For freshwater mussels in coastal rivers of eastern North America Sepkoski and Rex (1974) found that drainage basin area was the best predictor of the number of species, with the relationship between number of mussel species and catchment area being best described by a power function.

That the power function between number of fish species and drainage area provides the best fit for four out of six permanent, unpolluted stream systems of this study does not mean that the power function should necessarily be the best fit in all cases. The author agrees with Connor and McCoy (1979) that as yet the theoretical basis for power functions or any other type of functions between the number of species and the amount of living space remains to be proven.

Where streams have been disturbed by considerable long-term influences (e.g. channelization, pollution) the number of fish species declines in comparison with that in undisturbed streams or sections of the same streams (e.g. Harrel *et al.* 1967; Gorman and Karr 1978; Bauer *et al.* 1978). Such disturbance may be expected to disrupt the

relationship between fish species richness and catchment area and stream length. This appears to be confirmed by the results gained by analysis of the unpolluted and polluted sections of the South Esk River.

Species diversity H did not increase significantly downstream in both creeks, No well supported evidence for changes in H for fish in streams emerges from the literature. Harrel *et al.* (1967) found that species diversity did increase downstream whilst Evans and Noble (1978) found that species diversity was independent of location in the stream but dependent on depth. The trend in H from this study should be treated with caution as both the streams are small with a relatively low number of fish species.

The concept of stream order as proposed by Horton (1945) and modified by Strahler (1954) was suggested as being suitable for the biological analysis of streams by Abell (1961) and Kuehne (1962). A number of investigators (e.g. Kuehne 1962; Harrel *et al.* 1967; Lotrich 1973; Whiteside and McNatt 1972, Horwitz 1978; Cadwallader 1979) have shown that there is a progressive increase in the number of fish species with increasing stream order though in general this increase in fish species richness does not show the quantum jump in species numbers required if the number of fish species were closely dependent on stream order. While Strahler's modification of Horton's system has been the most used, it does have some limitations. For example, a large number of side streams of a lower order can enter a particular section of a higher order stream without altering the order; yet, from the biological point of view, the habitat may have been changed considerably. Seemingly biologically important attributes, such as stream volume or surface area, may be changed considerably without there being a change in stream order. Some of the objectives to the Strahler-Horton system have been overcome by further modifications, e.g. Shreve (1957), Scheidegger (1965). The application of these various modifications may lead to a lack of equivalence between investigations. To the biologist the application of a stream order system may give rise to units which are too gross and indiscriminant to subtle changes to be of much value.

In the case of both Parson's Bay Creek and Seven Creeks the relationships between the number of fish species and stream order are considerably poorer than those between number of fish species and catchment area or stream length. Evans and Noble (1979) found that changes in the order of a stream were not marked by significant changes in fish community structure and they concluded that changes in fish community structure and number of fish species were along a longitudinal continuum rather than an abruptly graded sequence. Thus it may be more ecologically useful to use in the analysis of longitudinal changes in stream communities a continuous variable such as catchment area or stream length.

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Abell, D.L. 1961. The role of drainage analysis in biological work on streams. *Verh. Int. Verein. Theor. Angew. Limnol.* 24, 533-537.

Barbour, C.D. and Brown, J.H. 1974. Fish species diversity in lakes. *Am. Nat.* 108, 473-489.

Bauer, B.H., Branson, B.A. and Colwell, S.T. 1978. Fishes of Paddy's Run Creek in the Dry Fork of the Whitewater River, southwestern Ohio. *Ohio J. Sci.* 78, 144-148.

Bennison, G.L. 1975. *An Ecological Method of Classification of the Coal River in South-east Tasmania*. B.Sc. Honours thesis, University of Tasmania.

Cadwallader, P.L. 1979. Distribution of native and introduced fish in the Seven Creeks River system, Victoria. *Aust. J. Ecol.* 4, 361-385.

Connor, E.F. and McCoy, E.D. 1979. The statistics and biology of the species-area relationship. *Am. Nat.* 113, 791-833.

- Evans, J.W. and Noble R.L. 1979. The longitudinal distribution of fishes in an East Texas stream. *Am. Midl. Nat.* 101, 333-343.
- Gorman, O.T. and Karr, J.R. 1978. Habitat structure and stream fish communities. *Ecology* 59, 507-515.
- Gray, D.N. 1961. Interrelationships of watershed characteristics. *J. Geophys. Res.* 66, 1215-1223.
- Gregory, K.J. and Walling, D.E. 1973. *Drainage Basin Form and Process — A Geomorphological Approach*. Edward Arnold, London.
- Haas, P.H. 1975. Some comments on use of the species-area curve. *Am. Nat.* 109, 371-373.
- Hack, J.T. 1957. Studies on longitudinal stream profiles in Virginia and Maryland. *U.S. Geol. Survey Professional Paper* 294B, 53-63.
- Harrel, R.C., Davis, B.J., and Dorris, T.C. 1967. Stream order and species diversity of fishes in an intermittent Oklahoma stream. *Am. Midl. Nat.* 78, 428-436.
- Hocutt, C.H. and Stauffer, J.R. 1975. Influence of gradient on the distribution of fishes in Conowingo Creek, Maryland and Pennsylvania. *Chesapeake Sci.* 16, 143-147.
- Horton, R.F. 1945. Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology. *Geol. Soc. Amer. Bull.* 56, 275-370.
- Horwitz, R.J. 1978. Temporal variability patterns and the distributional patterns of stream fishes. *Ecol. Monogr.* 48, 307-321.
- Hynes, H.B.N. 1970. *The Ecology of Running Waters*. Liverpool University Press, Liverpool.
- Kaesler, R.L., Herricks, E.E. and Crossman, J.S. 1978. Use of indices of diversity and hierarchical diversity in stream surveys. In *Biological Data in Water Pollution Assessment: Quantitative and Statistical Analyses*. ASTM STP 652 (Eds K.L. Dickson, J. Cairns Jr, and R.J. Livingston) pp 92-112. American Society for Testing and Materials, Philadelphia.
- Kuehne, R.A. 1962. A classification of streams, illustrated by fish distribution in an eastern Kentucky Creek. *Ecology* 43, 608-614.
- Lake P.S. and Fulton, W. 1981. Observations on the freshwater fish of a small Tasmanian coastal stream. *Pap. Proc. R. Soc. Tas.* 115 163-172.
- Larimore, R.W. and Smith P.W. 1963. The fishes of Champaign County, Illinois as affected by 60 years of stream changes. *Bull. Ill. St. Nat. Hist. Surv.* 28, 299-382.
- Laxton, R.R. 1978. The measure of diversity. *J. theor. Biol.* 70, 51-67.
- Leopold, L.B. and Maddock, T. 1953. The hydraulic geometry of stream channels and some physiographic implications. *U.S. Geol. Survey Professional Paper* 242, 1-52.
- Lotrich, V.A. 1973. Growth, production and community composition of fishes inhabiting a first-, second-, and third-order stream of eastern Kentucky. *Ecol. Monogr.* 43, 377-397.
- MacArthur, R.H. and Wilson, E.O. 1967. *The Theory of Island Biogeography*. Princeton University Press, Princeton.
- Nilsson, S.G. and Nilsson, I.N. 1978. Breeding bird community densities and species richness in lakes. *Oikos* 31, 214-221.
- Norris, R.H. 1978. *The Ecological Effects of Mine Pollution on the South Esk River (North-east Tasmania)*. Ph.D. Thesis, University of Tasmania.
- Pielou, E.C. 1975. *Ecological Diversity*. Wiley-Interscience, New York.
- Preston, F.W. 1962. The canonical distribution of commonness and rarity: Part I. *Ecology* 43, 185-215.
- Ricker, W.E. 1973. Linear regressions in fishery research. *J. Fish Res. Bd. Can.* 30 409-434.
- Scheidegger, A.E. 1965. The algebra of stream-order numbers. *U.S. Geol. Survey. Professional Paper* 525B, 187-189.
- Sepkoski, Jr. J.J. and Rex, M.A. 1974. Distribution of freshwater mussels: coastal rivers as biogeographic islands. *Syst. Zool.* 23, 165-188.
- Sheldon, A.L. 1968. Species diversity and longitudinal succession in stream fishes. *Ecology* 49, 193-198.
- Shreve, R.L. 1966. Statistical law of stream numbers. *J. Geol.* 74, 17-37.
- Sloane, R.D. 1976. *Interrelationships between Native and Introduced Freshwater Fish in Two Rivers in South-east Tasmania*. B.Sc. Honours Thesis, University of Tasmania.
- Smart, J.S. and Surkan, A.J. 1967. The relation between mainstream length and area in drainage basins. *Water Resources Res.* 3, 963-974.
- Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. *Trans. Am. Geophys. Union.* 38, 913-920.
- Thompson, D.H. and Hunt, F.D. 1930. The fishes of Champaign County: a study of the distribution and abundance of fishes in small streams. *Bull. Ill. State Nat. Hist. Surv.* 19, 5-101.
- Whiteside, B.G. and McNatt, R.M. 1972. Fish species diversity in relation to stream order and physicochemical conditions in the Plum Creek drainage basin. *Am. Midl. Nat.* 88, 90-101.

Observations on the Taxonomy of *Austrochiltonia* (Hurley) (Amphipoda: Ceinidae)

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A population of amphipods (*Austrochiltonia*), collected from Calvert's Lagoon in southern Tasmania, was classified using the only available diagnostic character, the morphology of the third uropod. Both described species were present (*A. australis*, 86.5%, *A. subtenuis*, 5.8%) as well as animals showing mixed uropod morphology (7.7%). Rearing experiments, in which offspring from females of all three 'types' were raised to maturity, revealed that 'australis' and 'australis/subtenuis' type females invariably produced 'australis' offspring, but 'subtenuis' type females surprisingly produced largely 'australis' offspring (92.7%) and only 1.8% 'subtenuis' type offspring (plus 5.5% mixed). These results raise serious doubts about the taxonomic validity of *A. australis* and *A. subtenuis* and in view of the ecological importance of the genus and its value in experimental laboratory studies a taxonomic review is recommended.

I. INTRODUCTION

The genus *Austrochiltonia* was erected by Hurley (1959) to include two endemic Australian species, *A. australis* (Sayce) and *A. subtenuis* (Sayce). The first of these is the type-species of the genus, being originally described by Sayce (1901) from material collected in Tasmania and Victoria. The genus was later rediagnosed and the two species redescribed by Williams (1962). Distribution is very broad through the southern part of the continent and a wide variety of habitats is utilised (Williams 1980).

Despite a detailed comparative study of *A. australis* and *A. subtenuis*, Williams (1962) was able to find only 3 characters to distinguish the species:

- differences in the relative length of the first antennae and the body;
- differences in the relative length of the flagellum and peduncle of the first antennae;
- the presence or absence of a ramus on the third uropod.

Williams (1962), observed that *these differences, as well as other morphological characters of a non-specific nature (e.g. gnathopods), exhibit a considerable degree of phenotypic variation.* The difference in the relationship between first antennae and body was least distinct and there was an indication that in both species the ratio altered with changes in body size. Although the relative length of the flagellum and peduncle of the first antennae were believed to provide a clear separation of the two species (Williams 1962), later unpublished work on *A. subtenuis* (Lim 1964) indicated that these lengths may also vary with size.

The character of most use to taxonomists has proved to be the presence or absence of a ramus on the third uropod. In *A. australis* this uropod possesses two segments with a clearly visible intersegmental joint between peduncle and ramus, whilst in *A. subtenuis* this appendage has only one segment in which a slight furrow may occasionally be observed (Williams 1962).

In the present study, the third uropoda of a large number of adult amphipods in Calvert's Lagoon, Tasmania, were examined to determine which of the two *Austrochiltonia* species inhabit the lagoon. It was found, as indicated by Williams (1962), that there was considerable morphological variation in the form of the third uropod. However, unlike the situation described by Williams (1962), animals could not always be

assigned unequivocally to one or other species. Since a preliminary search for alternative morphological criteria was unsuccessful, the possibility that a comparison of the uropod morphology of gravid females and their offsprings might provide useful information regarding the validity of the two species was investigated. The results of this investigation are presented here.

II. MATERIALS AND METHODS

Animals were collected from Calvert's Lagoon as part of a study by one of us (S.S.) on infection of *Austrochiltonia* by trematode metacercariae. Calvert's Lagoon is a permanent, shallow brackish pond, located on the South Arm Peninsula, south-east of Hobart.

Examination of the third uropod was facilitated by staining with acid fuchsin (Wagstaff and Fiddler 1955), followed by dissection using fine needles, mounting in *Euparal* and examination under a stereoscopic microscope.

Examination of an initial collection of 104 amphipods revealed that *A. australis* and *A. subtenuis* and mixed material was present. The proportions of each type and the criteria upon which our interpretation of identity were based were as follows:

— '*australis*' type — 86.5% — usually with a distinct intersegmental joint present and the ramus recessed into the peduncle (Figure 1c); other forms classed as '*australis*' varied from those in which the ramus was not recessed into the peduncle, but an intersegmental joint was clearly defined, to those in which a transverse crease occurred in the segment body in the same position as an intersegmental joint, but extended only part of the way across the segment, from a distinct 'notch' (thinning of the skeleton) on one side;

— '*subtenuis*' type — 5.8% — specimens in which there was either no evidence of an intersegmental joint, or there was a notch on one side of the segment, in the same relative position as an intersegmental joint, but no transverse crease (Figure 1e);

— '*australis/subtenuis*' type — 7.7% — specimens in which one third uropod was distinctly 2-segmented and the other 1-segmented (Figure 1d).

The observation that some specimens show both '*australis*' and '*subtenuis*' characteristics in their third uropoda suggests that some cross-breeding normally occurs. The programme to test this hypothesis was based on the premise that if the described taxa are genuinely distinct, the offspring of any gravid female should all belong to the same 'species-type' since that female will have mated only with the 'species' to which she herself belongs. Gravid females, collected at Calvert's Lagoon, were isolated singly in containers in the laboratory until they had released their young, on average 10 (range 7 — 22) days later. The third uropoda of the females were examined to identify the parent 'species'. The young of 14 '*australis*' type females were kept in one container, those of 3 '*subtenuis*' type females in another and those of 2 '*australis/subtenuis*' type females in a third container. The young were maintained in the laboratory, and after 2 to 3 months, when fully grown, the third uropoda of amphipods from each of the containers were examined as described above.

III. RESULTS

The results of the analysis of uropod morphology are presented in Table 1. It is clear from Table 1 that females of the '*australis*' and '*australis/subtenuis*' types produced young of the '*australis*' type only whereas females of the '*subtenuis*' type produced young

of all three types. It is unfortunate that, because of the low frequency of '*australis/subtenuis*' and '*subtenuis*' types in Calvert's Lagoon, so few gravid females of these types were available. Nevertheless, it seems surprising that such a low proportion (1.8%) of offspring from '*subtenuis*' females exhibited the same uropod morphology as their mother.

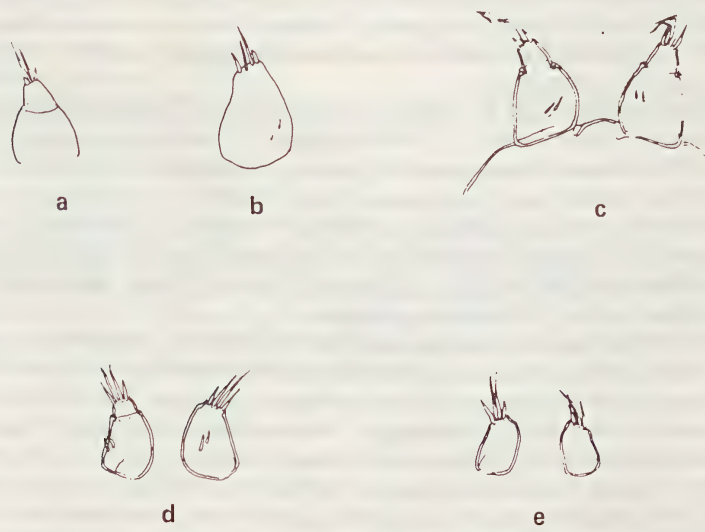


Fig. 1 Third uropod of *Austrochiltonia* spp. a, *A. australis*, (Williams 1962 Fig. 3N); b, *A. subtenuis*, (Williams 1962 Fig. 6D); c, '*australis*' type, Calvert's Lagoon, d, '*australis/subtenuis*' type, Calvert's Lagoon; e, '*subtenuis*' type, Calvert's Lagoon.

Table 1. Morphological variation in the third uropoda of offspring of *Austrochiltonia* females.

Parent type (N)	Number of off- spring examined (N)	Offspring type (%)		
		' <i>australis</i> '	' <i>australis/subtenuis</i> '	' <i>australis</i> '
' <i>australis</i> ' (14)	55	100	0	0
' <i>australis/ subtenuis</i> ' (2)	19	100	0	0
' <i>subtenuis</i> ' (3)	55	92.7	5.5	1.8

IV. DISCUSSION

The results of our investigation are in marked contrast to the observations of previous workers. Williams (1962) reported that at Casterton, Victoria, where both *Austrochiltonia* species were collected in more or less equal proportions, examination of a large number of third uropoda revealed no example that could be regarded as intermediate in form. Lim and Williams (1971) briefly reported that attempts to cross eight *A. subtenuis* males with eight *A. australis* females and *vice-versa* were unsuccessful, although control intraspecific crosses did produce live young. However, the test conditions employed were apparently very poor and only very low numbers of young were produced by the control crosses (Lim 1964, *pers. comm.*)

In Victoria, coloration of the eggs of *A. australis* and *A. subtenuis* is reported to be distinct, with *A. australis* having yellowish eggs and *A. subtenuis* green eggs (Lim and Williams 1971). However, in Calvert's Lagoon, both '*australis*' type and '*subtenuis*' type *Austrochiltonia* usually have green eggs. Colour variation of amphipods in Calvert's Lagoon has been shown to be related to infection by trematode cysts (Smith 1981) with infected individuals gradually changing from blue-green to yellow-orange. It is possible that parasitism might also influence egg colour in *Austrochiltonia*, thus accounting for the differences reported in Victoria specimens.

Only *A. australis* has been recorded from New South Wales, whereas both *A. australis* and *A. subtenuis* have been recorded from Victoria and Tasmania, and only *A. subtenuis* has been recorded from South Australia and Western Australia. This distribution may reflect clinal variation in the morphology of *Austrochiltonia*. Lim and Williams (1971) noted that *Austrochiltonia*, which occurs in many temporary water bodies and newly formed farm dams, has efficient dispersal mechanisms, and suspected that birds are involved. In this regard it is worth noting that *A. australis* was found on a duck which was shot at Sandford, near Calvert's Lagoon (Tasmanian Museum and Art Gallery records). The morphometric differences found by Williams (1962) in specimens of *A. australis* and *A. subtenuis* from a lagoon at Casterton, Victoria, may be due to the heterogeneity of origin of amphipods in that lagoon. Morphologically dissimilar amphipods may have been transported to the lagoon from widely separated and distinct habitats.

Although the morphology of the third uropod has been used extensively to distinguish between the two described species of *Austrochiltonia*, the results of the investigation reported here indicate that distinction on the basis of this character is questionable. The situation found at Casterton, in which the proportions of the two species are approximately equal and uropod morphology remains distinct, favours continued acceptance of both species. However, the situation found at Calvert's Lagoon, in which 7.7% of the total population exhibit mixed uropod morphology, gravid females exhibiting such mixed uropod morphology produce apparently healthy offsprings, and almost 93% of the young from clearly identifiable gravid *A. subtenuis* exhibit uropods characteristic of *A. australis*, strongly suggests a degree of cross-breeding unlikely between separate taxa. Since the other characters used by Williams (1962) also give inadequate separation, and since neither Williams nor ourselves have found suitable alternative characters, the status of *A. australis* and *A. subtenuis* as separate taxa must be considered doubtful.

It is hoped that the results presented here will stimulate a more intensive review of the taxonomy of *Austrochiltonia*. The problem is not simply of academic interest; *Austrochiltonia* is the dominant benthic crustacean genus in many freshwater habitats throughout much of the Australian continent and consequently is a key organism in many ecological studies. The genus has already proved its value as a laboratory test

organism in metal pollution studies (Lake *et al.* 1979) and its use in toxicity studies can be expected to increase following the recognition of its potential by Williams (1981) and Mills *et al.* (1979).

Lake, P.S., Swain, R. and Mills, B. 1979. *Lethal and Sublethal Effects of Cadmium on Freshwater Crustaceans*. Australian Water Resources Council. Technical Paper No. 37, Department of National Development, Canberra.

Lim, K.H., 1964. *The Biology of Austrochiltonia subtenuis* (Sayce). M.Sc. Thesis, Monash University.

Lim, K.M. and Williams, W.D. 1971. Ecology of *Austrochiltonia subtenuis* (Sayce) (Amphipoda, Hyalellidae). *Crustaceana*, 20, 19-24.

Mills, B., Lake, P.S. and Swain, R. 1979. *Two Freshwater Crustaceans Suitable for Toxicity Tests in Australian Waters*. Water Studies Centre, Technical Report No. 10, Caulfield Institute of Technology, Melbourne.

Smith, S.J. 1981. *The Trematode Fauna of Brackish Coastal Lagoon in Tasmania*. Ph.D. Thesis, University of Tasmania.

Williams, W.D. 1962. The Australian freshwater amphipods. I. The genus *Austrochiltonia* (Crustacea:Amphipoda:Hyalellidae). *Aust. J. Mar. Freshwater Res.* 13, 198-216.

Williams, W.D. 1980. *Australian Freshwater Life*. 2nd edition. Macmillan, Melbourne.

Williams, W.D. 1981. Biological Monitoring. In *An Ecological Basis for Water Resource Management*. (Ed. W.D. Williams) pp192-204. Australian National University Press, Canberra.

Wagstaff, E.R. and Fiddler, J.H. 1955. *The Preservation of Natural History Specimens. Volume 1. Invertebrates*. H.F. & G. Witherby, London.

